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The advantages and disadvantages of each test, based on the leaching characteristics of the fourteen wastes and the usefulness of each procedure as a standard test, are analyzed and compared. Finally, some comments on the need for careful interpretation of test results are provided.

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DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory, the Municipal Environmental Research Laboratory and the Office of Solid Waste, U.S. Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

The selection or design of any leachate test will ultimately be decided by a number of practical, rather than theoretical considerations. The classification of whether or not a waste is hazardous, via a leaching test, must assume less than ideal disposal conditions, in order that, its potential for causing environmental harm can be minimized. It is recognized that a single test will not be optimal for all disposal conditions. Nevertheless, from a regulatory point of view, developing different tests for each different waste and disposal option is clearly impractical and probably unworkable.

FOREWORD

This research effort is a combined response to an environmental need by two Office of Research and Development Laboratories. The Edison, New Jersey office of the Industrial Environmental Research Laboratory assisted the Municipal Environmental Research Laboratory in this effort.

The Industrial Environmental Research Laboratory-Cincinnati develops cost effective techniques to prevent, control, or abate multimedia (air, water, solid wastes, etc.) pollutional impacts associated with the extraction, transportation, processing, benefication, conversion, and use of mineral resources and with industrial processing and manufacturing. The Municipal Environmental Research Laboratory develops new and improved technology and systems for preventing, treating, and managing waste water and solid and hazardous waste pollutant discharges from municipal and community sources, for preserving and treating public drinking water supplies, and for minimizing the adverse economic, social, health, and aesthetic effects of pollution. The related pollutional impacts on our environment and the interplay between its components require a concentrated and integrated attack on the problem.

This report deals with the investigation of three leaching tests as reliable predictors of the potential environmental effects of the disposal of thirteen industrial wastes. The advantages and disadvantages of each test based on the leaching characteristics of the thirteen wastes and the usefulness of each procedure as a standard test are analyzed and compared. The report will provide data for decision makers of both government and industry alike contemplating residue leachate control from industrial sludge impoundment/municipal landfill co-disposal operations.

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ABSTRACT

A comparison of three leaching tests was performed with fourteen industrial wastes to evaluate the potential of each test for use as a standard leaching test. The study was done in conjunction with a background study on the development of a standard leaching test.

The advantages and disadvantages of each test, based on the leaching characteristics of the fourteen wastes and the usefulness of each procedure as a standard test, are analyzed and compared. Finally, some comments on the need for careful interpretation of test results are provided.

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ABBREVIATIONS AND SYMBOLS

TESTS

SLT—Leaching test developed by Ham et al. (1)
IUCS Test—I.U. Conversion Systems, Inc. Modified 48-hour shake leaching test
Minn. Test—Leaching test developed by the Minnesota Pollution Control Agency
Proc C—Procedure C} two procedures in the SLT
Proc R—Procedure R}
RLT—Leaching test using municipal landfill leachate
S/L—Solid/Liquid ratio or separation

LEACHATES

SL—synthetic municipal landfill leachate used in SLT
Acet—Acetate buffer used in Minn. Test
H_2O—distilled, deionized water leachate

WASTE SUPPLIERS

ECHO—Environmental Clearinghouse Organization, Inc.
Chem-Trol—Chem-Trol Pollution Services, Inc.

CHEMICAL ABBREVIATIONS

Na—Sodium
K—Potassium
Mg—Magnesium
Zn—Zinc
Cu—Copper
Cd—Cadmium
Pb—Lead
Cr—Chromium
Fe—Iron
COD—Chemical Oxygen Demand
Q—Quinoline
GS-MS—Gas Chromatography - Mass Spectrometry
TIRGC—Total Ion Reconstructed Gas Chromatogram

LIST OF WASTES—SEE TABLE 8

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SECTION 1

INTRODUCTION

Developing awareness of the potential of landfilled industrial wastes to pollute groundwater has led to an interest in a standardized test to discern the relative leaching potential of a waste. A background study on such a test done by the authors for the U.S. Environmental Protection Agency (EPA) is detailed in Ham, et al (1). During this background study a leaching test was developed, called the SLT. In order to evaluate the SLT, and other leaching tests which might be used as the standard test, a comparison of three leaching tests were made by running the tests on a wide variety of industrial wastes and comparing the relative ease, practicality and amount of information obtained in each of the tests. The tests used were the SLT, a 48-hour shake test developed by IU Conversion Systems, and a 24-hour acid leach test developed by the Minnesota Pollution Control Agency. The results of the test comparison are given in this report. Note that this test comparison serves as a practical evaluation of the workability of the SLT on a variety of wastes.

The development of the SLT and the SLT evaluation and test comparison are presented in separate reports in order to keep the length of each report reasonable.

SECTION 2

SUMMARY AND CONCLUSIONS

Three leaching tests, as specified by EPA, were used on 14 different industrial wastes, supplied by EPA, which were specifically chosen to be of widely differing characteristics. Some wastes were predominantly liquid, others were solid; some wastes were primarily inorganic, others organic; some wastes were complex with several distinct solids and/or liquid layers; and some were sticky or like glue and so were extremely difficult to handle. The SLT was the only test able to handle all wastes using only procedures specified by the test protocol. Note that no obviously dangerous (explosive, carcinogenic, etc.) wastes were tested, because such wastes would have provided little or no information beyond that provided using the 14 wastes.

The SLT test was the most aggressive of the three tests yielding the highest concentrations of inorganic parameters (mg/ℓ) 79% of the time, and the highest release of inorganic parameters (mg/kg waste) 55% of the time (Tables 12 and 13). It is the only test able to give information about both potential concentration and release of parameters leached from an industrial waste. Because the SLT is an aggressive test, providing information about what could happen in a worst case (but realistic) situation, its results need to be interpreted with care. For example, the concentration of leachate arising from large amounts of waste through which small amounts of water (leaching medium) are moving will probably approach the maximum concentration indicated by the SLT, but this may never happen with a particular landfill.

The importance of using different leaching media was indicated by the results. Acidic leaching media (pH 4.5) gave the highest concentrations of inorganic parameters 89% of the time, and the highest release 96% of the time (Table 14). Without the use of several leachates, test results could be very misleading and have no relation to the actual landfill for a particular waste.

Certain features of an ideal standard leaching test following the concepts discussed in section 4 are given in Table 1. An ideal leaching test is defined herein as a standardized procedure which works on all wastes and is able to predict quickly and with accuracy the potential water quality degradation within a landfill represented by the landfill disposal of a particular waste. It does not evaluate any changes in leachate quality arising from passage through soils or dilution. The major abilities and limitations of each test used in this study with regard to these features are given in Table 2. Column tests are not included in the concept of an ideal leaching test because of the difficulty of using a column test on a wide variety of wastes.

A number of different tests could be designed which meet the criteria of Table 1 and, yet, have considerable differences between them. Thus, once a standard leaching test has been designed, interpretation of the test results becomes a crucial factor in determining the applicability of the test. A standard leaching test provides a reproducible set of numbers that are a function of the interaction of a waste with a specific leaching solution under a specific set of conditions. It is up to the decision maker to evaluate those numbers and make a prediction regarding the behavior of the waste

TABLE 1. SOME FEATURES OF AN IDEAL STANDARD LEACHING TEST*

1. Use of leaching media corresponding to liquids likely to be in contact with the waste in the landfill (such as use of both an acid synthetic municipal landfill leachate and distilled water leaching solutions for modeling leaching in actively decomposing and stabilized municipal landfills, respectively).
2. Incorporates procedures to indicate both concentration and release of parameters likely to be leached from a waste.
3. Use of multiple elutions so secondary effects can be observed.
4. Use of an effective agitation procedure which does not unnaturally or unnecessarily abrade waste particles.
5. Use of a solid/liquid ratio high enough to minimize analytical and sampling errors, yet low enough to allow rapid determination of critical concentration and release information for most parameters.
6. Use of convenient, yet justifiable, elution times and numbers of elutions.

*It is assumed that any useable test would incorporate sampling procedures and sufficient replicates to gain statistical reliability.

TABLE 2. ABILITIES AND LIMITATIONS OF EACH TEST IN COMPARISON TO AN IDEAL TEST*

SLT

Positive aspects:

1. Use of two separate procedures to allow prediction of both concentration and release of parameters from waste.
2. Flexibility of leaching media selection such as the use of both acid synthetic municipal landfill leachate and distilled water as leaching solutions to model co-disposal with municipal solid waste.
3. Use of an effective, yet gentle, agitation technique.
4. Use of multiple elutions.
5. Use of an intermediate solid/liquid ratio which lessens the change of analytical errors of the Minn. test while generally allowing more rapid evaluation of release characteristics than does the IUCS test.
6. Incorporates procedures which allowed its direct use on all the wastes tested in this study.

Limitations:

1. Use of an oxygen sensitive leachate, required for proper modeling of leachate generated in actively decomposing municipal solid waste landfills.
2. The laboratory procedures and the amount of information obtained, especially if both concentration and release results are desired, require more laboratory effort and interpretive care.

IUCS TEST

Positive aspects:

1. Use of a generally effective agitation technique.
2. Use of multiple elutions.
3. Use of a high solid/liquid ratio gives relatively high concentrations of many parameters.
4. Use of a relatively straightforward laboratory procedure.

---

*i.e., Table 1.

(continued)

TABLE 2. (continued)

Limitations:

1. Use of only a distilled water leachate.
2. Lack of a procedure to evaluate the maximum concentration of a parameter in leachate.
3. Use of an elution time and number such that work needs to be continued over weekends.
4. Required adaptations on a waste by waste basis to allow some wastes to be tested.
5. The fewer numerical results require more careful interpretation and extrapolation of data than the SLT to apply the results to actual landfill situations.

MINNESOTA TEST

Positive aspects:

1. Use of both acid and distilled water leachates.
2. Simple and rapid to perform.

Limitations:

1. Acetate buffer models only one aspect of municipal solid waste leachate affecting its leaching aggressiveness.
2. Low solid/liquid ratio emphasizes subsampling, weighing, and analytical errors.
3. Use of only one elution gives much less information than either of the other two tests. No information is provided regarding the approach tostable results, the rate at which such stability is reached, or possible secondary effects.
4. Agitation technique allows significant concentration gradients in the bulk solution, raising the time needed to approach equilibrium and reducing the reproducibility of the results.
5. Required adaptations on a waste by waste basis to allow some wastes to be tested.
6. Neither concentration nor release information can be obtained with confidence because it is not known how close the results are after one elution to maximum values attainable or to practical values reached in actual landfills. Application of test results to actual landfills is difficult to justify.

in a landfill. Unfortunately, the multiplicity of factors affecting the leaching characteristics of a waste, both in the test and in the landfill, and the variability of landfill conditions, dictate that interpretation be done with care and with consideration of the waste and landfill characteristics. Test results should not be interpreted rigidly, e.g., developing criteria stating that a certain concentration of a given parameter in the test leachate automatically and without further consideration indicates that the waste is hazardous in the landfill. Rather, consideration should be given to such factors as the amount of waste to be disposed, the annual net infiltration of water in the area of the landfill, the factors affecting the leaching of the waste (as far as can be determined from the test results), possible waste—leachate interactions, and the fate of the landfill leachate after it leaves the waste and passes through additional wastes or soil.

As an example of the need for careful interpretation, consider the distilled water leachates from the CuO - Na_2SO_4 sludge. These leachates contained low concentrations of copper (<1 mg/l), yet very high concentrations of Na (~10,000 mg/l in the SLT Elution 1 leachates). With regard to Na, the leachate is probably not very hazardous, at least no more hazardous than sea water which has approximately the same Na concentration. Yet, in a landfill or in the soil underneath, the high ionic strength could solubilize potentially hazardous trace metals through ion exchange mechanisms. Thus, the leachate itself may not be hazardous, but it may solubilize hazardous materials in landfill environments. Likewise, several wastes (ink and paint waste, health and beauty care waste, food grade waste, and adhesive waste #6) released large amounts of unidentified organic compounds, as evidenced by the very high COD values in the distilled water leachates. The potential hazard of these wastes may not come from the organic compounds released by the waste, if these are not hazardous, but from the ability of the released organics to solubilize otherwise insoluble hazardous compounds, such as chlorinated organic pesticides or heavy metals. On the other hand, a waste may release small amounts of hazardous materials which will most likely be removed from the leachate by passage through the soil under the landfill. The waste might appear to be hazardous due to the release of this material, yet in the landfill it would actually be relatively innocuous. Several wastes which released trace metals in low concentrations might fall into this category. It should be noted that leaching modeled by the test in one or two days may simulate years of leaching in the field. During this time, bacteria may convert hazardous compounds into innocuous ones, or vice versa, or they may completely alter the leaching characteristics of a waste through their action on the waste matrix.

When interpreting test results, it is important to consider the physical condition of the landfilled waste. For example, a waste which is landfilled in large stable chunks or with a stable impervious coating could behave far differently in a landfill than in a test in which it were ground. The test results need to be interpreted in light of the conditions around the waste and the condition of the waste itself in the landfill.

An evaluation of the hazardous nature of a waste must include an evaluation of the landfill environment. A waste's hazardous nature is a situation specific characteristic. A waste may be hazardous to an organism under one set of environmental conditions yet completely innocuous under a different set of conditions. Furthermore, its hazard may be organism specific; i.e., it may be hazardous to one organism and not to another under the same set of conditions. Thus, a determination of the hazardous nature of a waste must include an evaluation of its hazardousness to specific organisms under specific conditions.

The limitations of a standard leaching test and the care needed in interpreting the results do not mean that a standard test is not worth developing and using. A standard test should provide a rapid evaluation of the parameters that are likely to be leached from a waste, and an indication of their maximum concentrations in the leachate and the total amount to be released per unit weight of waste. That the test is not perfect in predicting the long term leaching pattern of a waste or the precise concentration of a particular parameter in a particular landfill means that the test results need to be interpreted with care to avoid unnecessary expenditures for control of waste that are not actually hazardous in a particular landfill, or to avoid unexpected environmental degradation from improper land disposal of a waste.

In summary, of the three tests compared in this study, the SLT gave the most information in the shortest amount of time. The IUCS test could be improved if several modifications were incorporated, such as use of an acidic synthetic municipal landfill leachate when co-disposal of the waste being tested with municipal solid waste is possible, and if a procedure for measuring maximum concentration were added. The Minn. test would require several modifications in order to be a widely applicable standard test.

Whatever standard test is used, interpretation of test results is the crucial factor in determining the test's ultimate value in predicting whether a waste is hazardous when placed in a landfill. Virtually any leaching test which is properly interpreted would be more useful in making such a prediction than would be a well designed leaching test which is poorly interpreted.

SECTION 3

TEST PROCEDURES AND ANALYTICAL METHODS

LEACHING TESTS USED

The two tests used in addition to the SLT were selected by EPA as being among the best tests currently available and as having some variety in the test conditions. A survey of existing leaching tests by the Miter Corp. (2) gives a good overview of existing leaching tests.

The tests used in the test comparison were the SLT, an IU Conversion Systems modified 48-hour shake test (the IUCS test) and a test developed by the Minnesota Pollution Control Agency (the Minn. test). These tests are described in Tables 3, 4, and 5, respectively. There are several IUCS shake tests available, so particular care should be taken to specify the test conditions when discussing the test. A summary and comparison of the test conditions is given in Table 6.

In addition to the tests mentioned above, a municipal leachate was used as a leaching medium, using a modified SLT procedure R. The difficulty in working with highly air sensitive real leachate necessitated the modifications. The purpose of the real leachate test (RLT) (Table 7) was not to verify the accuracy of the synthetic leachate used in the SLT, as might be supposed, but rather to obtain an idea of the leaching ability of a real leachate sample. The leachate was not used as aggressively as the leachate upon which the synthetic leachate was modelled, and so cannot be used as a verification of the synthetic leachate.

WASTES USED

Ten of the wastes used in the test comparison were supplied by Environmental Clearinghouse Organization, Inc., Hazel Crest, Illinois, at EPA's request. Two wastes were supplied by Chem-Trol Pollution Services, Inc., Model City, New York, for the use in the background study and were reused in the test comparison. One of these, the wastewater treatment sludge, was used in only the SLT and the Minn. test. One locally obtained waste was also used. In addition, one waste termed papermill sludge (EPA), was used only in the SLT. The wastes, their sources, and the tests in which they were used are given in Table 8. Descriptions of the wastes and available chemical and physical analyses for the wastes are presented in tables at the start of the test results section for each waste.

WASTE SAMPLE PREPARATION

Since the intent of the comparison was to evaluate the tests themselves, the sample preparation procedure was kept the same for all tests. This preparation included a solid/liquid separation procedure that is recommended for sample preparation in the SLT background study (1). This technique is not included in either the IUCS or Minn tests. Both of

TABLE 3. SLT TEST PROCEDURE

Preparation of Sample

1. Representative samples of waste are taken using standard techniques appropriate for waste (e.g., ASTM standard techniques for sampling wastes) when available.

2. Wastes that are not obviously solid are separated into solid and liquid components, using the suggested solid/liquid separation scheme. Percentage solid (net weight) in waste is measured or estimated.

3. The liquid portion of the waste is analyzed directly. If the liquid is hazardous, an assessment is made of the total waste's hazardousness due to the liquid component. If the waste is assessed as hazardous, the test is terminated.

4. The moisture content of the solid component of the waste is determined by drying at 105°C for 24 hours, or other procedure as appropriate. The waste sample used for moisture content determination is discarded.

Selection of Leaching Solution

Leaching solutions are selected for use in the test based on the type of landfill into which the waste might be disposed, as follows:

Landfill	Leaching Solution
stabilized municipal landfill or monolandfill	distilled deionized water[*]
actively decomposing municipal landfill	synthetic municipal landfill leachate[†]
co-landfilled with other wastes in industrial landfill	distilled, deionized water[*], plus other leaching solutions deemed useful for modeling industrial landfills.

SLT Procedures

The solid portion of the waste sample is leached with the selected leaching solutions using two elution procedures—C and R—described

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[*] Meeting ASTM Specifications D-1193 for distilled, deionized water, or equivalent.

[†] A synthetic municipal landfill leachate, of pH 4.5, and composed of: 0.15M acetic acid, 0.15 M sodium acetate, 0.050 M glycine, 0.008 M pyrogallol, and 0.024 M ferrous sulfate.

(continued)

TABLE 3 (continued)

below. Elution time, temperature, agitation technique, and filtration procedure are the same for both elution procedures. Sufficient replicates are run for statistical reliability.

Elution time—an elution time of 24 hours is used for all elutions.

Temperature—the test is conducted at ambient temperatures (~20°C) unless major changes occur in waste characteristics at temperatures close to 20°C. In such cases the test is run at 20°C constant temperature.*

Agitation—a circular shaker tilted such that the shaking circle radius is vertical or nearly vertical is used. Square or rectangular flasks are used so that the waste gently tumbles through the leaching solution as the flasks turn. The rotation speed is 2-3 rpm.

Sample bottles—square or rectangular flasks are needed. Glass or plastic may be used, depending on parameters to be analyzed.

Procedure C (for estimation of maximum concentration)

1. In the first elution, leachate is added to the waste solid to give a solid/liquid ratio of one part waste by weight (dry weight) to ten parts leaching solution by volume (e.g., 1 gm (dry weight) waste to 10 ml leaching solution). The sample used in the test should not be dried prior to use. The total leachate volume used should be more than three times the leachate volume needed for analysis.
2. The sample is agitated for 24 hours, then filtered through a 0.45 micron pore size filter, using the filter aids described in the solid-liquid separation scheme as necessary (1). The filtered waste is discarded.
3. A sample of the filtered leachate, not more than one-third of the total volume, is removed for analysis. The volume of the remaining leachate is measured and the leachate returned to the test flask. Fresh waste is added to give a solid-liquid ratio of 1:7.5.
4. Step 2 is repeated.
5. A sample of the filtered leachate, not more than one-half of the filtered volume, is taken for analysis. The volume of the remaining leachate is measured and the leachate returned to the test flask. Fresh waste is added to give a solid-liquid ratio of 1:5.
6. Step 2 is repeated, and the filtered leachate is used for analysis.

(continued)

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*If other temperatures are more suitable for modeling a particular landfill, appropriate temperatures can be used but should be noted.

TABLE 3 (continued)

Procedure R (for estimation of maximum release)

1. In the first elution, leachate is added to the waste to give a solid-liquid ratio of one part waste by weight (dry weight) to ten parts leaching solution by volume (e.g., 1 gm (dry weight) waste to 10 ml leaching solution).

2. The sample is agitated for 24 hours, then filtered through a 0.45μm pore size filter, using the filter aids described in the solid-liquid separation as necessary. The filtered leachate is used for analysis.

3. The filtered waste is returned to the test flask and fresh leachate added. The same leachate volume used in the first elution is used maintaining the 1:10 solid-liquid ratio.

4. Step 2 is repeated.

5. Step 3 is repeated.

6. Step 2 is repeated.

7. The test is terminated and the waste discarded unless an indicator parameter (e.g., pH) indicates that the waste continued to have a major effect on the leaching solution, in which case the elutions are continued until the indicator parameter returns to baseline value.

An example of test procedures C and R using a model waste is given below. The waste is assumed to have a moisture content of 50% after the solid-liquid separation.

Procedure C	Procedure R
Elution 1	
120 gm wet weight (60 gm dry weight) is added to 540 ml leaching solution. (1:10 solid/liquid ratio).	40 gm weight (20 gm dry weight) of waste is added to 180 ml leaching solution. (1:10 solid/liquid ratio).
Agitate 24 hours at room temperature, filter	

(continued)

TABLE 3 (concluded)

Procedure C	Procedure R
Elution 2	
Discard filtered waste. Remove 150 ml leachate for analysis. Measure remaining leachate and return to flask. If remaining volume is 450 ml, add 120 gm[*] wet weight waste. (1:7.5 solid/liquid ratio.)	Remove filtered leachate for analysis. Return filtered waste to flask and add 200 ml fresh leachate. (1:10 solid/liquid ratio.)
Agitate 24 hours at room temperature, filter	
Elution 3	
Discard filtered waste. Remove 150 ml filtered leachate for analysis. Measure remaining leachate and return to flask. If remaining volume is 300 ml, add 120 gm[†] wet weight waste. (1:5 solid/liquid ratio.)[‡]	Remove filtered leachate for analysis. Return filtered waste to flask and add 200 ml fresh leachate. (1:10 solid/liquid ratio.)
Agitate 24 hours at room temperature, filter	
Discard filtered waste. Use filtered leachate for analysis.	Remove filtered leachate for analysis. If indicator parameter indicates more elutions are needed, return waste to flask and add 200 ml fresh leaching solution and continue elutions until indicator parameter returns to base line value. Otherwise discard waste.

[*] $$450 \text{ ml} \times \frac{1 \text{ gm waste (dry)}}{7.5 \text{ ml leaching solution}} \times \frac{2 \text{ gm waste (wet)}}{1 \text{ gm waste (dry)}} = 120 \text{ gm waste (wet weight)}$$

[†] $$300 \text{ ml} \times \frac{1 \text{ gm waste (dry)}}{5.0 \text{ ml leaching solution}} \times \frac{2 \text{ gm waste (wet)}}{1 \text{ gm waste (dry)}} = 120 \text{ gm waste (wet weight)}$$

[‡] Note that leaching media lost by removal of used waste will approximately equal the liquid added with the new wet waste.

TABLE 4. DESCRIPTION OF THE IUCS MODIFIED 48 HOUR SHAKE TEST

SCOPE

This method covers the determination of the long-term diffusion-controlled leachate properties of a soil or waste material. The procedure is to establish representative values of the long-term diffusion-controlled leachate properties of a soil or waste material as placed in embankments, landfills, and other disposal or use sites. These properties result from prolonged water contact both on the surface of the soil or waste materials and on a portion of the interior of a mass of soil or waste material as limited by the permeability coefficient of the material.

PROCEDURE

1. Measure an aliquot of water specific for the field site or standard water as defined by ASTM Committee D-19 such that the ratio of ml of water to g, dry weight, of test specimen is 4 to 1. IUCS typical practice is to use 500 g., dry weight, of specimen to 200 ml of water. Record measured water volume in liters.

2. Add the measured water to the specimen of predetermined surface area and weight which was placed in a non-leaching container.

3. Seal container and place in the box carrier of a reciprocating shaker at an oscillation rate of 60 to 70 one-inch strokes per minute. Be certain that placement of the container allows for maximum water movement.

4. Shake container for 48 hours.

5. Immediately after the shake period, sample a 100 ml aliquot for total suspended solids analysis. Vacuum filter at least 500 ml of the remaining leachate using .45 micron membrane or glass fiber filters.

6. Decant off any leachate left in the non-leaching container, allowing the test specimen to remain in the container. Note and record the condition of the test specimen, being sure to include comments on physical deterioration. These comments shall be as quantitative as possible to facilitate any necessary modification in apparent surface area for subsequent 48-hour shake periods.

7. Repeat steps 1 through 6 four times, thus obtaining five sets of leachate, each set consisting of one 100 ml aliquot of unfiltered leachate to be analyzed for total suspended solids and one 500 ml aliquot of filtered leachate.

TABLE 5. DESCRIPTION OF THE MINNESOTA TEST

12.5 gm dry weight of solid is placed in a 1000 ml separatory funnel. 500 ml of eluent (distilled, deionized H_2O or pH 4.5 acetate buffer) is added, the sample is shaken for 60 seconds, allowed to stand for 24 hours, shaken for another 60 seconds, then filtered through a Whatman #42 filter.* The first 10 ml of filtrate are discarded and the remainder is kept for analysis.

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*For purposes of this study, the resulting filtrate was then filtered through a 0.45 micron filter to maintain consistency in filtering technique for all tests.

TABLE 6. A SUMMARY OF THE LEACHING TESTS USED IN THE TEST COMPARISON

	SLT	IUCS Test	Minnesota Test
Leaching Solution	Synthetic Leachate H_2O*	H_2O*	Acetate Buffer, H_2O*
Solid/Liquid Ratio	1:10 (Process R) Varied (Process C)	1:4	1:40
Shaking Technique	Slow Tumbling	Back and Forth Shaking	1 min. shake, 24 hr. rest
Time per Elution	24 hrs	48 hrs	24 hrs
Number of Elutions	3 or more	5	1
Temperature	Room	Room	Room

*Distilled, deionized water.

TABLE 7. DESCRIPTION OF THE REAL LEACHATE TEST

(Leachate Collected August 13 from a Madison Landfill)

Leachate was collected in fifteen 250 ml acid-washed glass prescription bottles. Four bottles (3 wastes + 1 duplicate) had the wastes to be leached already inside. A solid/liquid ratio of 1:10 was used. Eight bottles were used to anaerobically store the leachate until use in the experiment, and three bottles were collected to store leachate for a daily background analysis during the duration of the test. The test bottles were stored at room temperature and shaken intermittently throughout the day. After a 24-hour elution time, the leachate was decanted from the prescription bottles into screw top polycarbonate centrifuge tubes. The tubes were closed then centrifuged for 20-30 minutes at 10,000 RPM on a Sorvall Centrifuge, then filtered through a 0.45 micron membrane filter. Sufficient leachate was filtered for analysis. (Even after centrifugation, the filtering process was slow.) pH readings were taken as rapidly as possible, however, even in a few minutes a brown flocculant precipitate formed. After the readings were taken, the leachate was acidified to approximately pH 1 and stored at 4°C until analysis. The four waste sample bottles plus one background bottle were sampled daily. The background sample was split into two aliquots, and each aliquot sampled and analyzed separately. New leachate was used for each of the three elutions.

Leachate Background Values

COD ~ 27,200 mg/l
Cond ~ 1×10^4 μmhos/cm
pH - 5.5 (varied from 5.15-5.81)
Na - 465 mg/l ± 15 (range)
K - 720 ± 40 mg/l
Mg - 250 ± 10 mg/l
Fe - very unstable (variable)
Zn - 31 ± 1 mg/l
Cu ~ 1 mg/l, unstable

TABLE 8. WASTES USED IN THE TEST COMPARISON

	Waste	Waste Abbreviation	Source	Test Used in
1.	Adhesive Waste #1		ECHO	SLT, Minn, IUCS
2.	Ink & Paint Waste	I.P.W.	ECHO	SLT, Minn, IUCS
3.	Coal Tar Waste		ECHO	SLT, Minn, IUCS
4.	Health & Beauty Care Waste	H.B.C	ECHO	SLT, Minn, IUCS
5.	Food Grade Waste		ECHO	SLT, Minn, IUCS
6.	Adhesive Waste #6		ECHO	SLT, Minn, IUCS
7.	Petrochemical Industry Water/Oil Sludge	Petrochemical Sludge	ECHO	SLT, Minn, IUCS
8.	Grain Processing Lipids & Fats	Grain Fats	ECHO	SLT, Minn, IUCS
9.	Food Wastes, Clay		ECHO	SLT, Minn, IUCS
10.	Marble Wash		ECHO	SLT, Minn, IUCS
11.	Copper Oxide-Sodium Sulfate Sludge	CuO-Na_2SO_4 Sludge	Chem-trol	SLT, Minn, IUCS -RLT
12.	Electroplating Sludge	EPS	Local	SLT, Minn, IUCS -RLT
13.	Wastewater Treatment Sludge	WTS	Chem-trol	SLT, Minn, -RLT
14.	Papermill Sludge, EPA	PMS-EPA	Chem-trol	SLT

these tests, however, were designed for solid or semi-solid wastes rather than for predominantly liquid wastes. As many of the wastes used in the test comparison were predominantly liquid, the designers of both the IUCS and Minn tests were asked how to prepare predominantly liquid wastes for their tests.* Both agreed that a solid/liquid separation might be one approach to sample preparation, although both emphasized that their tests were not designed for such wastes, and that a solid/liquid separation might not be the approach they would use to prepare predominantly liquid wastes for their tests.

Different wastes required different sample preparation procedures. The preparation used for each waste is given in the tables at the start of the test results section for each waste.

SELECTION OF MEASUREMENT PARAMETERS

Inorganic

Several trace metals were selected for analysis in leachates from tests on the wastes supplied by ECHO, Inc. Selection, made by EPA in consultation with the authors, was based on their prevalence in the waste as determined by ECHO, Inc. and on their general toxic nature. These metals are listed as "metals of interest" in the table at the start of each waste's data section.

Other parameters were measured to obtain an overview of the leaching process (conductivity, pH) or in order to have additional parameters with which to compare the leaching tests (Na, K, Mg, various trace metals).

Organic

COD was measured as a general indicator of organic materials in leachate. With the exception of coal tar waste, identity of leachable organic compounds which might be present in a waste was not known. Therefore, a first step in analysis of leached organic compounds was identification of organic compounds present in the waste. Once these were identified, compounds were chosen for analysis in leachates, in order to evaluate the ability of different leaching solutions to solubilize organic compounds of differing polarity. Compounds were classified as polar, slightly polar or nonpolar.

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*B. Roberts and C. Perket, respectively.

ANALYTICAL METHODS

Analytical methods for determination of inorganic parameters and COD are given in Table 9. These procedures are all from Standard Methods (3).

For organic parameters, except COD, identification and analysis of a parameter was much more complicated, as discussed previously. The first step in analysis was a determination of major organic constituents of a waste. A standard method for determination of an unknown organic compound in a waste of unknown composition and consistency was not available, so a method, described below, was devised for preparing a hexane extract of a waste for analysis on gas chromatography-mass spectrometry.

1. Ten grams of the solid portion of a waste (i.e., after the liquid/ separation step) were placed in an extraction thimble.
2. The waste was extracted with 100 ml hexane for six to eight hours in a soxhlet extraction apparatus.
3. The hexane extract, brought to 100 ml volume if necessary, was analyzed using gas chromatography—mass spectrometry.
4. Major peaks in the reconstructed ion chromatogram were analyzed to see if the mass spectra could be identified.

A Finnigan model 1015 gas chromatograph—mass spectrometer was used in conjunction with a Finnigan 6110 MS data analysis system. This procedure allowed the identification of several compounds in the extracts from several wastes. The adhesive wastes could not be analyzed by this method, since both wastes solidified during analysis and clogged the apparatus they were in at the time of solidification. (One glued the GC injection syringe shut.) Hexane extracts from several wastes contained precipitates. The analytical procedure for evaluating waste organic composition was sufficient for this study, but obviously it is not a complete analysis of all wastes.

Mass spectra of major peaks were identified either using a computer comparison with spectra of known compounds, or by major peak comparison with published spectra. If the identified compound was available, identification was confirmed by running a standard and comparing retention times and mass spectra.

The ink and paint waste was chosen for organic analysis because of the variety of the identified compounds, and because the high COD levels in the ink and paint waste leachates indicated that high concentrations of organic compounds were being leached.

TABLE 9. ANALYTICAL METHODS FOR ROUTINE OR INORGANIC ANALYSES

Parameter	Method	Instrument	~Det. Limit (mg/l)
pH	probe		
Specific conductance	cell		
Redox potential	probe		
Chemical oxygen demand	Acid-dichromate reflux (3)		
Na	Atomic Emission	Perkin-Elmer Model 460	
K	Atomic Emission	Perkin-Elmer Model 460	.05
Mg	Atomic Absorption	Perkin-Elmer Model 460	.05
Zn	Atomic Absorption	Perkin-Elmer Model 460	.10
Fe	Atomic Absorption	Perkin-Elmer Model 460	
Cu	Atomic Absorption	Perkin-Elmer Model 460	.05
Pb	Atomic Absorption	Perkin-Elmer Model 460	0.25
Cd	Atomic Absorption	Perkin-Elmer Model 460	
Cr	Atomic Absorption	Perkin-Elmer Model 460	

Ink and paint waste leachates were extracted with methylene chloride using a procedure based on the ASTM procedure for the extraction of oil and grease from water (4). Three 3 ml extractions from a measured amount of leachate (approximately 75 mls) were made. The extractions were dried with anhydrous sodium sulfate, brought to 10 ml total volume, then analyzed using GC - MS. Quantification was done by comparing peak areas in the TIRGC with peak areas of standards run under the same conditions. The pH of the leachates were not altered prior to extraction. Methylene chloride was used rather than hexane primarily because the higher density of methylene chloride simplified the solvent - leachate separation.

For the coal tar waste, a good estimation of the compounds of interest was available without having to use GC - MS identification. Coal tar wastes are known to frequently contain phenols and cresols. The leachates from the coal tar wastes were distilled according to the procedures given in Standard Methods (3) for the analysis of phenols. The distillates were analyzed using GC - MS. In addition to phenol and cresol, naphthalene and quinoline were also identified in the distillates. Standards for all four compounds were run and the amounts in the distillates determined. Since the distillation procedure is not a standard method for analyzing napthalene or quinoline, the recovery of these compounds from the original leachate is unknown. The same procedure was used for all leachate samples; their relative concentrations can be compared. The measured concentrations and releases for napthalene and quinoline may be underestimates of the actual concentrations.

REPRODUCIBILITY

Replicates were run throughout the test series on most wastes. Generally the replication was good. Replicates are plotted separately on the data figures for each waste, allowing a visual estimation of the reproducibility. Generally the replication for the acid and distilled water leachates in all tests were comparable.

In addition to the above use of replicates, 18 replicates were run on a single waste (a paint waste from an auto assembly plant) with synthetic leachate: nine replicates using SLT procedure R and nine using SLT procedure C. Six parameters were determined. (pH was also measured, but as the pH of the synthetic leachate was not affected by the paint waste, the pH value in the leachates did not vary.) The mean values and standard deviations for each parameter on each of the three elutions are presented in Table 10. The deviations are for the complete test, and include errors due to waste subsample differences, test procedures, leachate instability, and analytical procedures. Fe data also include errors in weighing the $FeSO_4$ used in the synthetic leachate. The standard deviations are generally under 15% unless near the detection limit. The consistent exceptions are Zn and Fe in procedure C, which have quite high deviations. Why the Zn data should show a high variation in procedure C and not in procedure R, particularly on the first day when they are replicates, is unknown. The Fe data in procedure C show that over a three-day period, a significant amount of Fe is precipitating out of solution. This precipitation illustrates a compromise made in the SLT.

TABLE 10. STANDARD DEVIATION CALCULATIONS FOR MULTIPLE REPLICATES OF PAINT WASTE LEACHED WITH SYNTHETIC LEACHATE USING SLT PROCEDURES

		Procedure R (N = 9)			Procedure C (N = 9)			Both Procedures Day 1*		
Parameter	Day	Mean Value	σ	%	Mean Value	σ	%	Mean Value	σ	%
K	1	3.86	0.16	4.1	4.00	0.17	4.3	3.93	0.17	4.7
	2	2.10	0.22	10.7	6.49	1.84	28.3			
	3	1.58	0.18	11.6	10.50	0.49	4.7			
Mg	1	9.9	0.87	8.8	8.6	0.69	8.1	9.3	1.1	11.9
	2	1.4	0.07	4.9	16.3	2.3	14.0			
	3	0.51	0.03	6.1	33.	7.5	22.7			
Zn	1	16.92	1.31	7.74	22.68	10.33	45.6	19.4	7.8	40.
	2	3.40	0.23	6.8	70.5	22.5	31.9			
	3	1.44	0.08	5.4	123.	51.	41.3			
Pb	1	0.52	0.02	4.4	0.50	0.03	6.0	0.51	0.025	5.0
	2	0.27	0.02	8.2	0.93	0.14	15.4			
	3	0.22	0.04	17.2	1.32	0.18	13.8			
Cu	1	b.d.†			b.d.					
	2	b.d.			b.d.					
	3	b.d.			0.32	0.09	28.3			
Fe	1	1180.	87.	7.4	1123.	71.	6.4	1152.	80.	7.0
	2	1166.	80.	7.0	904.	146.	16.3			
	3	1094.	58.	5.6	585.	204.	35.			

*On Day 1, procedures C and R are the same.

†b.d. = below detection.

In order to model the anaerobic nature of municipal landfill leachate, an anaerobic synthetic leachate is used. However, working with the synthetic leachate under completely anaerobic conditions (filtering in a glove bag, etc.) is too complicated for a routine test. Therefore, an anaerobic leachate which has some redox buffering capacity was designed and the lack of perfect redox control accepted as a necessary compromise. The loss of iron in procedure C over the three-day period is a result of this compromise. A non-anaerobic synthetic leachate, described by Ham, et al (1) avoids the problem by not modeling the anaerobic nature of municipal landfill leachate. Note that the Fe concentrations in the procedure R leachates are relatively stable, indicating minimal loss of Fe due to oxidation-precipitation.

Standard addition was used to determine the detection limits for different metals and to determine if any matrix effects could be seen in the synthetic leachate. Various amounts of K, Mg, Cu, Zn, Pb, and Cr were added to fresh synthetic leachate and analyzed using atomic absorption or emission. The results indicated no major matrix effects in the analysis of any of the metals. The detection limits estimated for each metal are given in Table 9.

RELEASE CALCULATIONS

The release of a parameter per unit mass waste for each of the tests was calculated using the equation given below:

$$\text{Release}_{\text{elution(i)}} = \frac{(\sum_{i=1}^{N} \text{Conc(i), mg/l})(\text{leachate volume, ml})(\text{1 L/1000 ml})}{(\text{dry weight of solid in test, g})(\text{1 kg/1000 g})}$$

where i is the elution number and n the total number of elutions. Leachate volume and dry weight of solid is constant for each test, except for SLT procedure C. Calculation of release in SLT procedure C is more complicated and is described in Ham, et al (1). Since the purpose of procedure C is to evaluate maximum concentration, release using this procedure was not calculated. Except for unusual release patterns, release in procedure R will be greater than or equal to that in procedure C.

SECTION 4

TEST COMPARISON

There are a number of ways to compare the different leaching tests. A comparison can be made of the concentrations in the different test leachates of a single parameter leached from a waste. This has been done in Table 11 for the more important or interesting parameters from selected wastes. The table indicates the aggressiveness of each test and the wide range in results from three tests designed to indicate the same thing—the leaching characterics of a waste. This single parameter comparison does little good in understanding the relative aggressiveness of the tests, however, unless the factors affecting the parameter concentrations in the leachates are known.

The relative aggressiveness of the tests can also be analyzed by comparing the number of times each test gave the highest concentration (or release) of a parameter for all the parameters analyzed throughout the test comparison. This is done in Tables 12 (concentration) and 13 (release). As can be seen, the SLT gave the highest concentration or release much more frequently than the other tests. Table 14 shows a similar comparison for acid and water leachates, comparing only parameters that are measured in both. Obviously, the acid leachates are much more aggressive than distilled water leachates. Such a comparison is good for analyzing the general aggressiveness of a test.

A more complete comparison of the tests entails an analysis of the effects of the differences between the tests on the test results, and the importance of these differences for interpreting the test results. A list of the major test variables or factors which must be set in developing a standardized leaching test is provided in Table 15. As the effects of the different components or factors of the tests were not analyzed separately, but rather the tests were compared as whole units with several factors differing between them, it is not possible to isolate the effect of any one factor and explain differences between the tests as being due due to that specific factor. Rather, it is only possible to say that a given factor varied between tests and in some cases it seems reasonable to ascribe a given difference in the test results to this factor. The major factors will be discussed individually in the following sections.

LEACHATE COMPOSITION

The profound effect of leaching solution composition on the materials and concentrations leached from a waste is shown with several wastes used in the test comparison, most notably CuO - Na_2SO_4 sludge. Acidic leachates—the synthetic leachate and the acetate buffer—leached potentially hazardous trace metals in significant concentrations that were either below detection or leached in very low concentrations in the water leachates (Figure 1). This is not surprising, since many metals are more soluble in

TABLE 11. A SUMMARY OF TEST COMPARISON RESULTS FOR SELECTED PARAMETERS FROM SELECTED WASTES

Waste	Concentration, mg/l							Release, mg/kg				
	SLT				IUCS	MINN.		SLT		IUCS	MINN.	
Parameter	SL* Proc C	SL* Proc R	$H_2O^\dagger$ Proc C	$H_2O^\dagger$ Proc R	$H_2O^\dagger$	Acet‡	$H_2O^\dagger$	SL* Proc R	$H_2O^\dagger$ Proc R	$H_2O^\dagger$	Acet‡	$H_2O^\dagger$
Ink & Paint Waste:												
Na				190	455		35		2410	2862		1400
K		24.5		10	30.5	9	2.5	505	169	274	360	100
Mg		23		5.5	18	1.9	1.3	292	83	137	72	52
Zn		36		0.27	1.17	38	0	681	2.7	5.8	1520	0
Pb		4.2		0	0.24	10.2	0	85.5	0	0	406	0
Cu		0.20		0.34	1.15	0.14	0.09	3.8	3.9	5.3	5.6	0
Cd		0.28		0	0	0.11	0	4.2	0	0	4.4	0
Cyclohexanone		176		260	435	54	115	2580	3750	4120	2170	4700
Napthalene		0.31		0.65	0.65	1.3	1.64	6.9	6.6	4.0	52	65
COD				41,500					480,000			
Coal Tar Waste:												
Napthalene	12.7	21.9	20.1	20.9	5.7	2.8	2.4	624	578	81.2	112	96
Phenol	493	96	193	112	679	2.6	2.7	1644	1949	472	104	108
Cresol	138	58.5	80.2	58.1	36.5	1.4	1.3	1290	1338	288	56	52
Quinoline	307	93.5	64.0	620	26	0	0	2176	1726	333	0	0
COD			2250	730					15,390	4492		4560
Health & Beauty Care Waste:												
Zn	25.0	12.8	11.0	5.9	11.5	2.9	1.4	174	73	67	116	56
Cd	0.92	0.39		0.14				6.0	1.4			
Fe			122	37.0	81.0	52	11		543	440	2080	440
Cu	5.60	1.55	14.0	5.9	10.0	9.6	1.5	38	112	79.2	384	60
Pb	0.86	0.69	0	0	0	0.40	0.21	18.8	0	0	16	8.4
COD			93,600	12,670	33,600				149,000	186,000		

(continued)

TABLE 11 (continued)

Waste	Concentration, mg/l							Release, mg/kg				
	SLT				IUCS	MINN.		SLT		IUCS	MINN.	
Parameter	SL* Proc C	SL* Proc R	$H_2O^†$ Proc C	$H_2O^†$ Proc R	$H_2O^†$	Acet‡	$H_2O^†$	SL* Proc R	$H_2O^†$ Proc R	$H_2O^†$	Acet‡	$H_2O^†$
Food Industry:												
Zn	1.8	2.0	0	0	0	1.5	0	51	0	0	60	0
Pb	0.95	3.8	0	0	0	6.5	0	56	0	0	260	0
COD			340	190	128		4		3340	1800		160
Marble Wash:												
Pb	0.60	0.63	0	0	0	3.5	0	16.6	0	0	140	0
COD			142	128	116		72		2230	1576		2880
$CuO-Na_2SO_4$ Sludge												
Na			42,000	9,740	23,000		4970		220,000	170,000		207,000
K	32.4	5.2	39	4.30	24	4.4	3.5	171	90	140	185	150
Mg	3281	1970	153	132	6.4	380	12	43,200	6734	104	15,300	616
Cu	2916	3120	0.57	0.38	0.27	1450	0.18	104,000	6.9	2.0	74,200	13.6
Zn	7.65	6.84	0.20	0	0.12	3.7	0	155	0.6	0.7	155	2
Fe			1.55	0.1	0.31	120	0.18		3.8	2.2	5,100	18
Electroplating Sludge:												
Zn	45	160	0	0	0	210	0	6,570	0	0	9,540	0
Cd	7.50	19.9	0	0	0	7.4	0	943	0	0	344	0
Wastewater Treatment Sludge:												
Zn	2.0	18.0	1.0	1.0		11	0	460	23		800	0
Cu	200	290	0	0		85	28	5,800	0		6,050	350
COD			5,500	1,800		0			23,000			

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*SL - synthetic municipal landfill leachate.

†H_2O - distilled, deionized water.

‡Acet - acetate buffer, pH 4.5.

TABLE 12. THE NUMBER OF TIMES EACH TEST LEACHING SOLUTION GAVE THE HIGHEST CONCENTRATION OF AN INORGANIC PARAMETER FROM A WASTE FOR THE DIFFERENT TEST LEACHATES

	SLT						
	Proc C		Proc R		Minn.		IUCS
	H_2O	SL	H_2O	SL	Acet	H_2O	H_2O
Na	8	--*		--	--		4
K	1	10					1
Mg	1	7		1	1		
Fe	1	--	1	--	1		
Zn		6		5	2		
Pb		1		1	4		
Cu	1			2			1
Cd				2			
COD	4	--		--	--		
Total Number	16	24	1	11	8	0	6
Total, %	60.6		18.2		12.0	0	9
Total for Each Test, %	SLT 79%				Minn. 12%		IUCS 9%

*Not measured.

TABLE 13. THE NUMBER OF TIMES EACH TEST LEACHING SOLUTION GAVE THE HIGHEST RELEASE OF AN INORGANIC PARAMETER FROM A WASTE FOR THE DIFFERENT TEST LEACHATES

	SLT Procedure R		Minn.		IUCS
	H_2O	SL	Acetate	H_2O	H_2O
Na	5			2	5
K		8	4		
Mg	1	8	2		
Fe	1		2		
Zn		8	4		
Pb		1	5		
Cu		1	2		1
Cd		2	1		
COD	2			1	1
Total Number	9	28	20	3	7
Total %	13	42	30	4.5	10.5

	SLT	MINN.	IUCS
Total for each test, %	55%	34.5%	10.5%

TABLE 14. THE NUMBER OF TIMES ACID OR H_2O LEACHING SOLUTIONS GAVE HIGHEST CONCENTRATIONS OR RELEASE OF AN INORGANIC PARAMETER FROM A WASTE

(Only for Parameters Measured in Both Acid and H_2O Leachates)

	SLT		Minn.		IUCS	Total		
	Acid(SL)	H_2O	Acid	H_2O	H_2O	Acid	H_2O	TOTAL TESTS
			Number of Times Giving Maximum Concentration					
K	10	1			1	10	2	12
Mg	8	1	1			9	1	10
Zn	11		2			13	0	13
Pb	2		4			6	0	6
Cu	2	1			1	2	2	4
Cd	1					1	0	1
						41	5	46*
					Total, %	89	11	
			Number of Times Giving Maximum Release					
K	8		4			12	0	12
Mg	8	1	2			10	1	11
Zn	8		4			12	0	12
Pb	1		5			6	0	6
CU	1		2		1	3	1	4
Cd	2		1			3	0	3
						46	2	48*
					Total, %	96	4	

*Totals are not equal because two tests may both give the maximum concentration but have different maximum releases. In cases where the maximum concentration or release were the same, the results were not tabulated.

TABLE 15. TEST FACTORS AFFECTING PARAMETER CONCENTRATIONS IN LEACHATES

1. Sampling Technique and Sample Pretreatment
    - A. Sampling technique in waste stream
    - B. Sample storage and shipment
        - age, temperature, air contact, mixing, etc.
2. Subsampling in Laboratory
3. Solid Sampling and Preparation
    - A. Particle size reduction
    - B. Particle size selection
    - C. Solid/liquid separation
    - D. Other preparatory procedures
4. Test Conditions
    - A. Leachate composition
        - pH, complexing, etc.
    - B. Solid/liquid ratio
    - C. Number of elutions
    - D. Agitation technique and surface area contact
    - E. Time per elution
    - F. Temperature
    - G. Waste or leachate replacement in each elution.
5. Separation Procedure after Leaching
6. Leachate Handling after Separation
7. Analysis

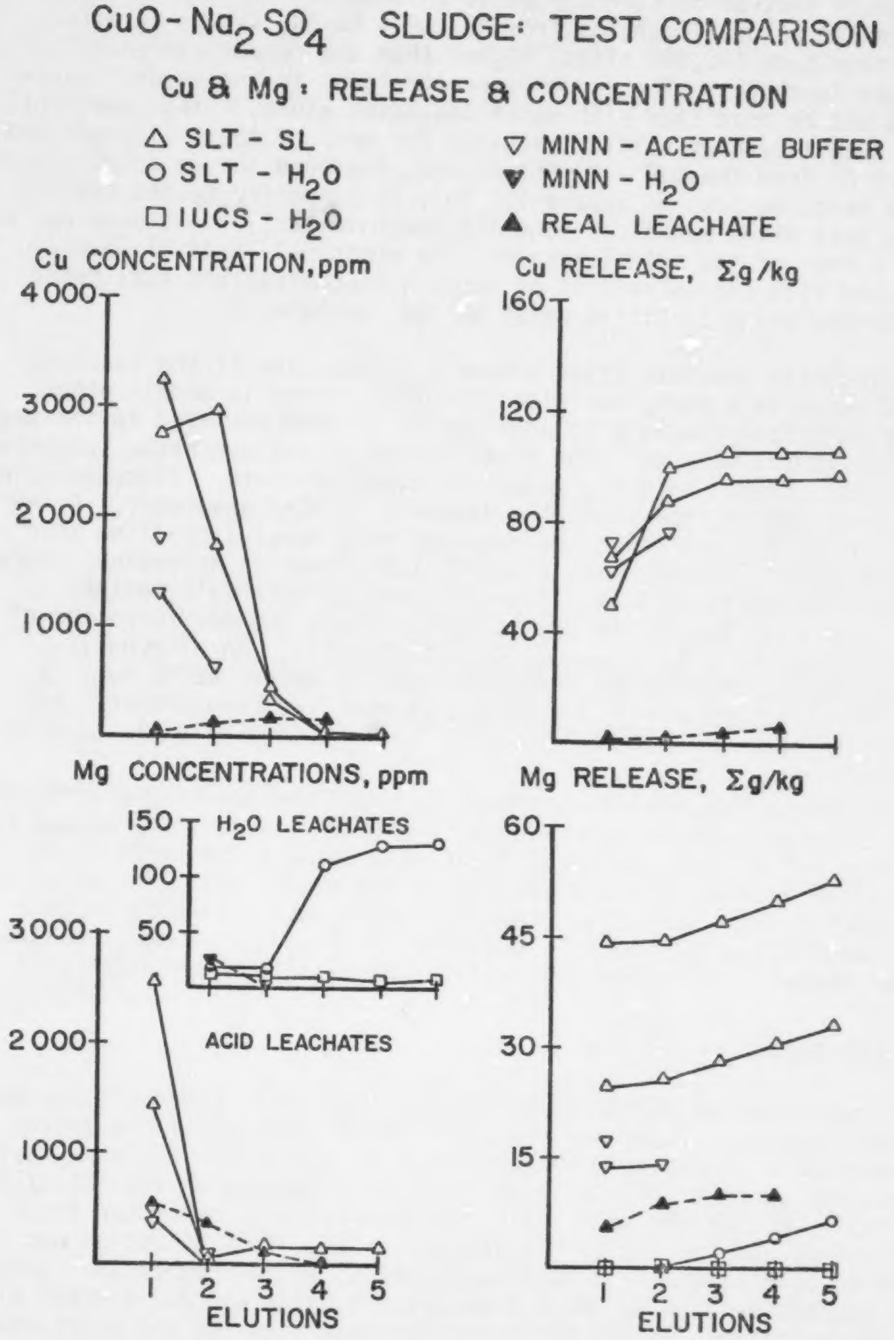


Figure 1. Cu and Mg concentration and release curves for CuO-Na$_2$SO$_4$ sludge, test comparison.
(Cu concentrations in all distilled water leachates were less than 0.6 ppm.)

acidic than in neutral or slightly basic solutions. The copper concentrations in the acidic leachates from the CuO - Na_2SO_4 sludge were four orders of magnitude (10,000 times) higher than the copper concentrations in the water leachates. The copper concentrations in the acidic leachates could not be predicted with water leachates alone. Since municipal landfills generally have acidic leachates for much of their lifespan and would leach Cu from the CuO - Na_2SO_4 sludge, the need for an acidic leachate in the leaching test is apparent. This is supported by the results of a leaching test using municipal landfill leachate (RLT). Although not as acidic as either of the acid leachates, the municipal landfill leachate still leached high concentrations of copper, concentrations that could not be obtained using distilled water as the leachate.

The synthetic leachate gives a more accurate view of the leaching that would occur in a young municipal landfill, since it models other aspects of municipal leachate in addition to pH when compared to the acetate buffer which models only pH. The disadvantage of the synthetic leachate comes from the attempt to fully model municipal leachate. Since municipal leachate is anaerobic, the synthetic leachate is also anaerobic. Being anaerobic, it is air sensitive and requires more careful handling than aerobic leachates. Furthermore, a precipitate forms on oxidation, introducing the possibility of a loss from solution of materials, either occluded in or adsorbed on the precipitate. Thus, improper handling of the synthetic leachate may cause inaccurate results. An alternative aerobic synthetic leachate has been developed as described in Ham, et al (1). This leachate avoids the oxidation-precipitation problem, but does so at the cost of not modeling real leachate as completely as does the anaerobic synthetic leachate.

The synthetic leachate is designed to model the leaching environment found in actively decomposing municipal landfills. Since many wastes will not be subjected to such leaching conditions, because the landfill is stabilizing or because of the placement of the waste, distilled water is used to model a less aggressive leaching situation. This also happens to model landfilling the waste in question by itself, or with stabilized industrial wastes. All three leach tests use distilled water for this purpose.

SOLID-LIQUID RATIO

The importance of the solid to liquid ratio could frequently be seen in the test results. There are several possible effects of the solid/liquid ratio on a parameter's concentration in leachate. For every soluble component, the concentration will be directly dependent on the solid/liquid ratio, simply because the more solid present, the more parameter there is to be dissolved and the higher the concentration. This situation was seen with very soluble parameters, such as Na and K, quite frequently. Good examples of this are the Na and K from ink and paint waste. A graph of the Na or K concentrations in the first H_2O leachate from ink and paint waste versus the amount of solid present per 100 ml leachate (Figure 2) shows that the Na or K concentrations fall nearly on a straight line. This indicates that the concentration in solution is directly dependent on the amount of solid present.

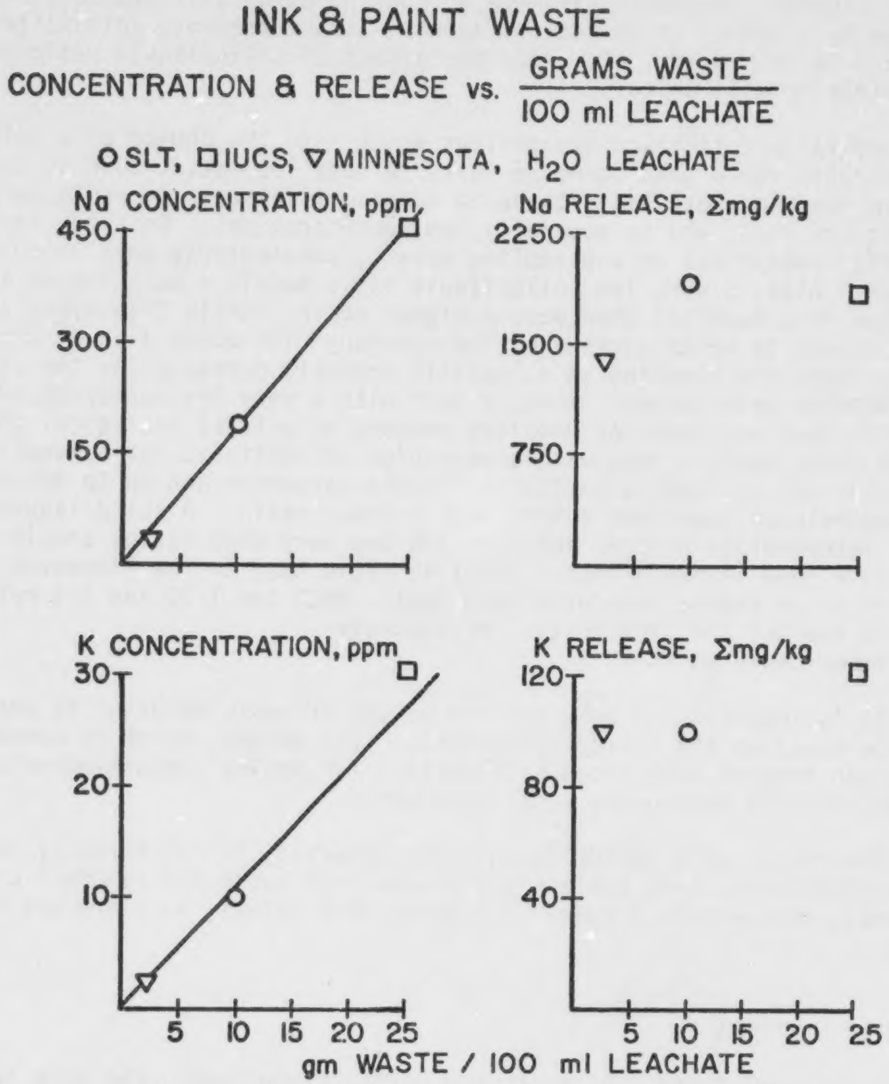


Figure 2. Variation in Na and K concentration and release for ink and paint waste with solid/liquid ratio (gm waste/100 ml leachate) using a distilled water leachate.

At the other extreme is a parameter whose concentration is controlled strictly by a solubility equilibrium. In this case, the concentration in solution would be independent of the amount of solid present and would be the same in all tests. Such a situation has not been encountered with the wastes studied. For most parameters, concentration will probably be controlled by a number of competing factors—amount present, solubility, sorption or desorption, etc.—and the effect of solid/liquid ratio on the concentration will be complex.

Several practical considerations enter into the choice of a solid/liquid ratio for a good standard test. A very low ratio, such as that used in the Minnesota test, leads to very small amounts of waste being used in the test, and to generally low concentrations. Both results emphasize analytical or subsampling errors, particularly when calculating release. Also, a very low solid/liquid ratio models a much longer leaching time in a landfill than does a higher ratio. While this might at first appear to be an advantage, the accuracy with which a short test models long-term leaching in a landfill probably decreases as the time span modeled gets longer. Thus, a test with a very low solid/liquid ratio is less accurate for modeling reasons as well as analytical ones. On the other hand, a test with a very high solid/liquid ratio requires more elutions to leach a partially soluble parameter and so to determine maximum release than does a test with a lower ratio. A solid/liquid ratio intermediate between the very low and very high ratios should be used in a good standard test. The 1:40 ratio used in the Minnesota test appears to be rather low for a good test. Both the 1:10 and 1:4 ratios used in the SLT and IUCS tests, respectively, and either could be used.

It is important to note how the weight of waste material is measured when calculating the solid/liquid ratio. Dry weight, which is commonly used, can present analytical difficulties for wastes containing volatile or semivolatile components other than water.

The choice of a solid/liquid ratio generally is not directly based on landfill conditions (unless calculated from waste and rainfall conditions), and, within a range of intermediate values, is therefore arbitrary.

MULTIPLE ELUTIONS

Both the SLT and IUCS tests use multiple elutions. Far more information can be obtained from these multiple elutions than from a single elution as used in the Minnesota test. The IUCS test uses five elutions, while the SLT uses three (unless the pH in the SL samples has not returned to below 5.0). The extra elutions in the IUCS test provide more information than the three elutions in the SLT, however, they also require more work. A compromise needs to be made between the added information obtained from the extra elutions, and the added work involved in obtaining it. One factor in the selection of the number of elutions for a standard leaching test is simply convenience. As long as there is no technical reason for selecting one number of elutions over another, the number of elutions chosen should be convenient for lab personnel. The IUCS test was more inconvenient than the other tests in that it required working on weekends. One of the reasons for selecting three elutions in the SLT was simply convenience. The test can be started on Monday, samples taken on Tuesday, Wednesday, and Thursday, with Friday left for analysis of the samples. Four elutions could also be taken without inconvenience.

Note that no matter how many elutions are chosen, an argument can always be made for using one more elution. For some wastes, one elution will give all the information obtainable from the waste; some wastes will require three elutions, some five, some fifty. There is no way of knowing the optimum number of elutions for a given waste without running extensive tests to determine when some acceptable degree of equilibration is reached. This, obviously, is contrary to the concept of a standard test. Selection of the optimum number of elutions should be based on the optimum number of elutions for a variety of extensively tested wastes, and on convenience. Experience with the SLT suggests that three elutions is generally adequate (1).

AGITATION TECHNIQUE AND SURFACE AREA OF CONTACT

The SLT and the IUCS tests had generally effective agitation techniques in that little particle abrasion was observed and particle and leaching media movement was sufficient to avoid visually obvious concentration profiles in the media. The Minn. test developed pronounced concentration differences which were observable between the liquid located near the waste particles and that located away from the particles when colored components were being leached. These concentration differences are not surprising, since the waste is not agitated for 24 hours following the initial shaking.

For two wastes, namely, the coal tar waste and the $CuO-Na_2SO_4$ waste, the SLT agitation method in itself appeared to be one reason for the higher release with the SLT test than with the IUCS test. In the SLT agitation procedure, the waste is always gently tumbling through the leachate. This exposes more surface area of the waste to leachate contact. The IUCS test agitation procedure did not provide such particle agitation of the waste, resulting in approximately the same waste surface being in contact with the leachate. With coal tar waste, the concentration of napthalene was higher in the SLT H_2O leachates than in the IUCS H_2O leachates (Figure 3). Given the physical nature of coal tar, it is reasonable to ascribe the higher concentrations to the greater surface area in contact with the leachate. Coal tar is impervious to water and viscous enough to inhibit internal diffusion. Thus, for unsaturated parameters, the concentration in leachate will depend on the surface area of contact with the waste.

Another probable example of the effects of agitation on release can be seen in the Na release from the $CuO-Na_2SO_4$ sludge (Figure 4). A comparison of the Na release in the H_2O leach SLT and IUCS tests shows a more rapid drop off in release in the IUCS test such that the fifth elution, for example, provided little additional release beyond that of the

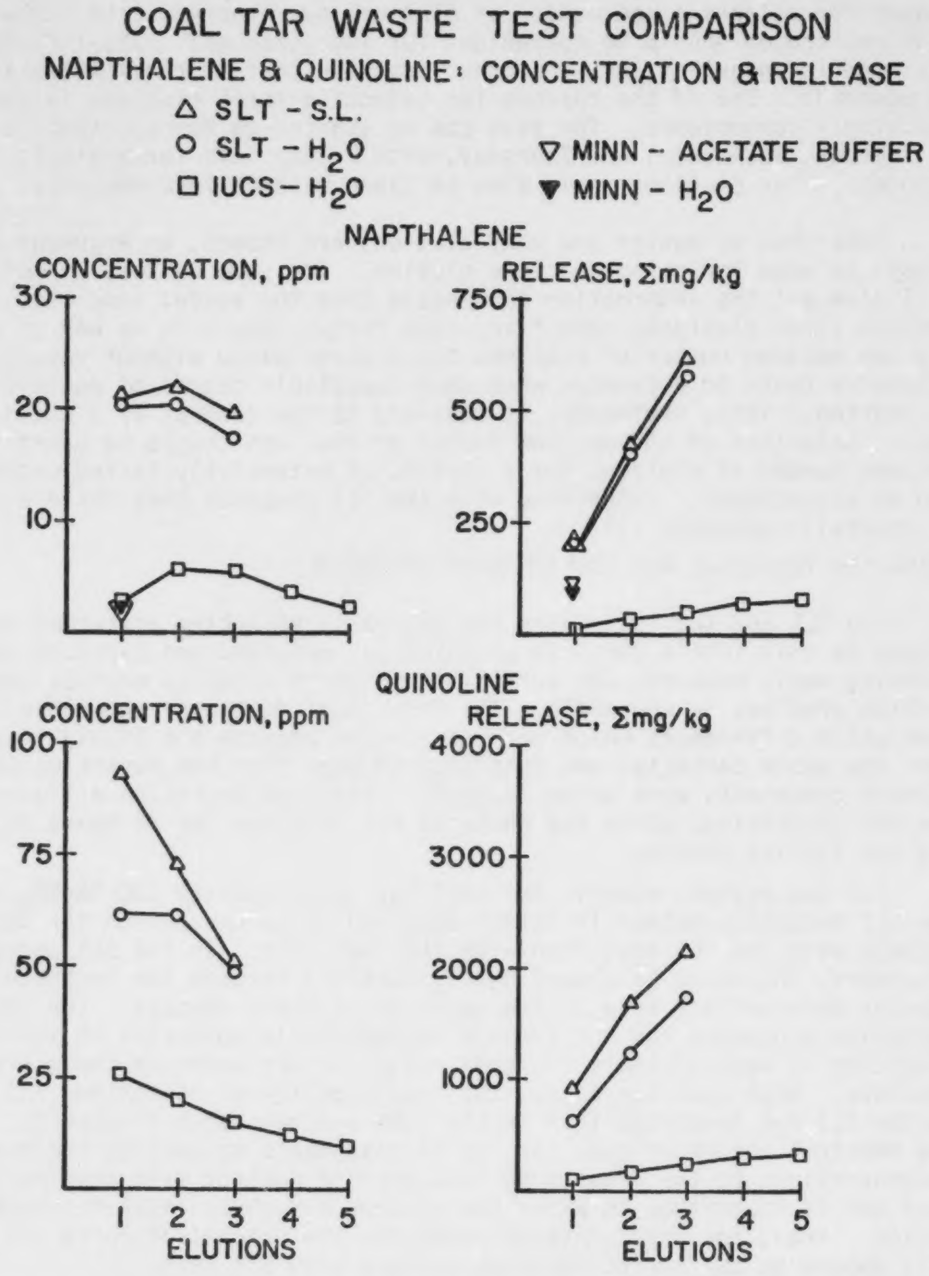


Figure 3. Napthalene and quinoline concentration and curves for coal tar waste, test comparison.

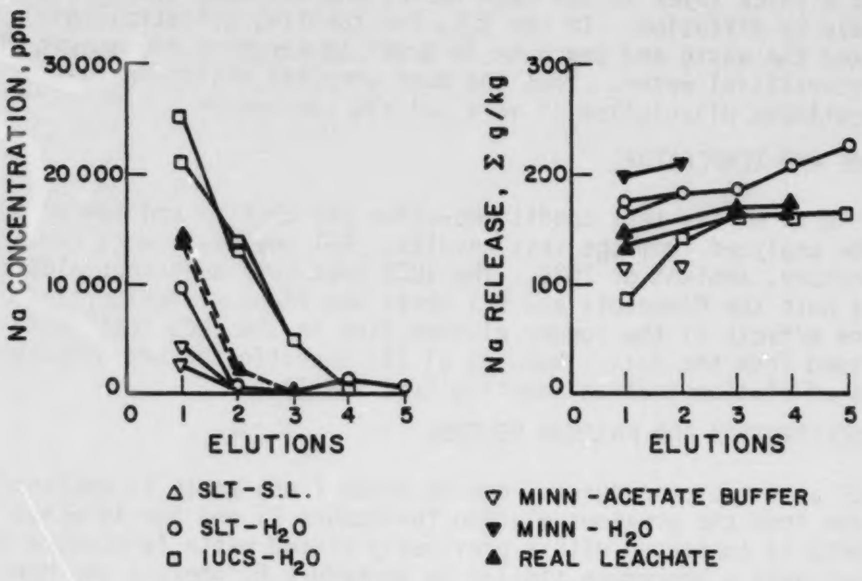


Figure 4. Na concentration and release from a CuO-Na_2SO_4 sludge in test leachates.

fourth elution. The SLT data indicate that the Na is continuing to be released in the later elutions. It appears that the waste in the IUCS test formed a thick layer in the test vessel and was subsequently released slowly by diffusion. In the SLT, the tumbling agitation constantly mixed the waste and leachate in order to minimize the amount of stagnant interstitial water. Thus the more complete mixing in the SLT promoted continued dissolution of very soluble components.

ELUTION TIME AND TEMPERATURE

The effects of two test conditions—time per elution and temperature—could not be analyzed from the test results. All the tests were run at the same temperature, ambient or 20°C. The IUCS test uses a 48-hour elution time, while both the Minnesota and SLT tests use 24-hour elution times. However, the effects of the longer elution time in the IUCS test could not be ascertained from the data. Ham, et al (1) investigated and discussed the effects of elution time on leaching test results.

MAXIMUM CONCENTRATION AND MAXIMUM RELEASE

The SLT uses two procedures: one in which fresh waste is contacted with leachate from the previous elution (procedure C) and one in which fresh leachate is contacted with a previously eluted waste (procedure R). The IUCS test uses a procedure similar to procedure R, whereas the Minnesota test uses only one elution. Procedure C gives an indication of what will happen to a given parameter as the leachate passes through a large volume of waste, i.e., the procedure will approximate or approach maximum concentrations or saturated conditions. As landfills will generally have very high solid/liquid ratios at a given time and the leachates could often be saturated, this information should be very useful. On the other hand, an estimation of the amount of a parameter potentially available to groundwater requires maximum release under landfill conditions per unit mass of waste. The two procedures in the SLT allow estimation of both maximum concentration and maximum release. Neither of the other tests, nor any other tests known to the authors, allow both estimations. The IUCS test gives an estimation of maximum release, since it also involves multiple leachings of the same waste sample. The Minnesota test, with only one elution, cannot be relied upon to provide either maximum concentration or release.

SOLID/LIQUID SEPARATION

Since the solid/liquid separation was run for all tests, a comparison of the behavior of separated versus nonseparated wastes is not possible. However, the procedure is unique to the SLT preparation and is not suggested for either the IUCS or Minnesota tests. (Neither of the latter tests gives directions for dealing with predominantly liquid wastes.) Some comments on the solid/liquid separation are therefore in order.

The IUCS test specifications read as follows:

> The procedure is to establish representative values of the long-term...leachate properties of a waste material as placed in...landfills and other disposal sites. (See Table 4.)

This certainly is one of the objectives of a standard leaching test. In a landfill, the solid and liquid components of the waste should separate as the liquid percolates down or is absorbed by surrounding material. Therefore, long-term leaching occurs on the solid portion of the waste. With the solid/liquid ratios used in the leaching tests, several years may be modeled by the tests. In this time span, certainly a solid/liquid separation will occur in the landfill. It is reasonable, therefore, to include a solid/liquid separation step in the preparation of wastes having liquid components. Furthermore, this preparatory step can make the test itself much easier. A waste such as ink and paint waste with a very low solids content (6% dry weight) in organic solvents would be very difficult to work with if not separated prior to the test. First, a 1:10 solid to liquid ratio on dry weight basis would be almost a 2:1 waste to leachate ratio on a wet weight basis. The leachate would make up only about one-third of the total liquid present. Second, the difficulties in separating the solid and liquid components in the ink and paint waste would only be exacerbated by mixing the waste with the leaching solution. Instead of a mixture of organic solvents with some solids, the waste would now consist of an emulsion with a very low solids content. Separating the liquid and solid components would now be even more difficult, and there would be more samples to be separated. A solid/liquid separation scheme prior to the test makes the test more realistic and simpler.

ORGANIC ANALYSIS

Several identified organic compounds were quantified in the coal tar waste and ink and paint waste leachates. Identified compounds were classified as polar, nonpolar, or slightly polar, as follows:

Polar:

- cyclohexanone
- phenol
- cresol

Nonpolar:

- aromatic ring compounds with aliphatic side chains:
  - xylene
  - isopropylbenzene
  - m-ethyltoluene

Slightly polar:

- quinoline

The release curves of the polar compounds from both wastes were similar and follow the general release curve for a very soluble compound. The acid leachates are no more effective at solubilizing these compounds than were the H_2O leachates, and in the case of cyclohexanone, considerably less effective.

Three of the four nonpolar compounds were not solubilized in either acid or H_2O leachates. Naphthalene was solubilized in both acid and H_2O leachates at about the same concentrations. These concentrations were lower and followed a different release pattern than found with polar compounds. In the coal tar waste leachates, napthalene appeared to be saturated.

Quinoline showed different behavior in acid and H_2O leachates, presumably due to its basic nature ($K_b = 3 \times 10^{-10}$). It would be expected to be more soluble in acidic than in neutral solutions, as was found in the leachates.

In short, the acid and H_2O leachates exhibited similar leaching aggressiveness towards polar and nonpolar organic compounds, while the acid leachate was more aggressive towards quinoline, which is a base.

SECTION 5

DETAILED RESULTS

The data are presented in the following format:

1. Description of the waste and a summary of the leaching test results.
2. Graphical presentation of the SLT data.
3. Graphical presentation of the test comparison data, including
    - A. SLT procedure R data,
    - B. IUCS test data, and
    - C. Minnesota test data
4. GC-MS Total Ion Reconstructed Gas Chromatograph

Mass spectra of identified TIRGC peaks are presented in the Appendix. The format for the description of the waste and summary of test results is given in Table 16. The physical and chemical descriptions of the wastes given by ECHO, Inc. or Chem-Trol, Inc. are presented as received. The analytical methods used for the determinations presented by the companies are not known.

The complete SLT data is presented separately from the test comparison data to avoid cluttering the test comparison graphs. SLT procedure R data are presented on both the SLT and test comparison graphs. The test comparison graphs thus present only half of the SLT data. The IUCS and SLT procedure R procedures are directly comparable.

A summary of the symbols used in presenting the SLT and test comparison data is given in Table 17.

A discussion of the results for wastes with particularly interesting leaching results follows the graphical presentation of the data.

TABLE 16. FORMAT FOR THE DESCRIPTION OF WASTES AND SUMMARY OF LEACHING TESTS RESULTS

Waste No.   Waste Name

Source

Physical description
Chemical analysis, if available

- inorganic
- organic

Sample preparation, including S/L sep. procedure. Special comments as necessary.

Maximum Concentration, mg/l

Acid leaching solutions

- Wisconsin test procedure C, SL
- Wisconsin test procedure R, SL
- Minnesota test, Acetate buffer

H_2O leachates

- Wisconsin test, procedure C
- Wisconsin test, procedure R
- IUCS
- Minn.

Maximum (Cumulative) Release, mg/kg Waste

Acid leaching solutions

- Wisconsin test, procedure R, SL
- Minnesota test, Acetate buffer

H_2O leachates

- Wisconsin test, procedure R
- IUCS test
- Minnesota test

TABLE 17. SUMMARY OF SYMBOLS USED IN PRESENTING SLT AND TEST COMPARISON DATA

Standard Leaching Test Symbols

△——△ Synthetic Leachate —Procedure C

○——○ Distilled, Deionized H_2O—Procedure C

△- - -△ Synthetic Leachate —Procedure R

○- - -○ Distilled, Deionized H_2O—Procedure R

Test Comparison Symbols

△ SLT—Synthetic Leachate

○ SLT—Distilled, Deionized H_2O

□ IUCS Test—Distilled, Deionized H_2O

▽ Minnesota Test—Acetate Buffer

▼ Minnesota Test—Distilled, Deionized H_2O

▲ Real Leachate Test

TABLE 18. ADHESIVE WASTE #1: DESCRIPTION AND SUMMARY OF RESULTS

Waste Number 1, ECHO, Inc.

Description:

An adhesive manufacturing waste, contains plasticizers DPB and SAIBF and resins polyvinyl acetate and styrene butadiene, as well as filler and pigments. It consists of large chunks of an amber colored gel, sticky to the touch, which melt at just over room temperature.

Analysis:

ECHO, INC.: pH (water slurry) 8.5, Ash 1.1%, Cd 0.87 ppm, Pb 3.31 ppm, Cr 0.61 ppm, Zn 6.74 ppm, Cu 1.04 ppm, no phenol.

Wisconsin: 99.7% volatile at 600°C, 66% volatile at 105°C for 24 hours, partically soluble in hexane and in acetone.

Organics: not analyzed, glued GC injection syringe shut.

Metals of Interest: Pb, Zn, Cu

Sample Preparation:

Obvious solid, cut into 1-inch cubes.

Comments:

Tests run at 20°C to prevent glue from melting. In a test at room temperature (25°C), the glue melted, then resolidified incorporating much of the leaching solution in the resolidified gel.

(continued)

TABLE 18 (continued)

Maximum Concentration and Release

Concentration		(mg/l)	
Acid leachates	Na	K	Zn
SLT procedure C, SL	----	9.0	0.84
SLT procedure R, SL	----	2.75	0.58
Minn. Acetate	----	0.85	0.32
H_2O leachates			
SLT procedure C	4.70	24.2	0.58
SLT procedure R	0.88	1.20	0.10
IUCS	7.0	0.15	B.D.
Minn.	1.3	0.05	0.34

Release		(mg/kg)	
Acid leachates	Na	K	Zn
SLT procedure R, SL	----	65	15
Minn. Acetate	----	34	6.8
H_2O leachates			
SLT procedure R	15.9	14.4	2.8
IUCS	40.7	2.7	2.0
Minn.	52.	20.	0.

Pb, Cu: all samples below detection.
B.D.: below detection.

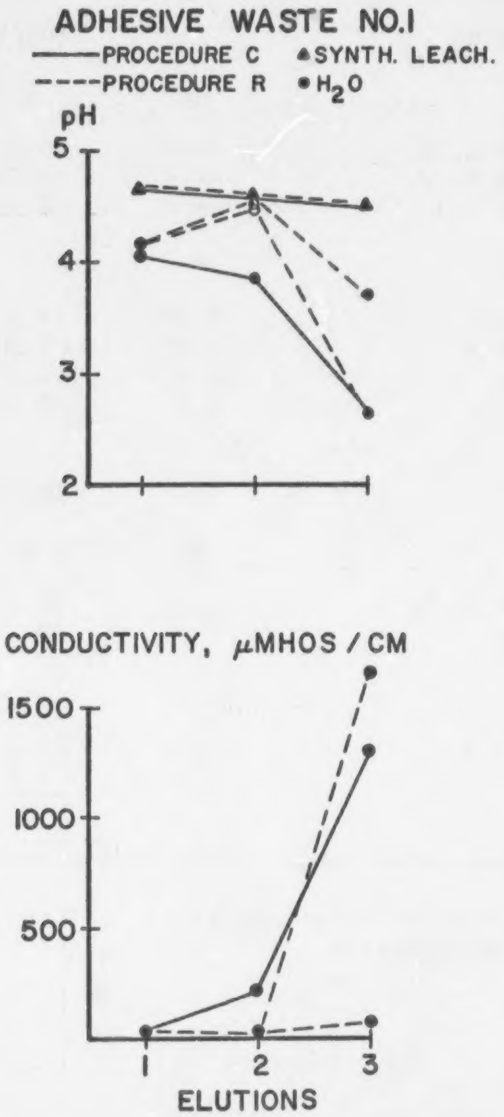


Figure 5. pH and specific conductance curves for adhesive waste #1, SLT.

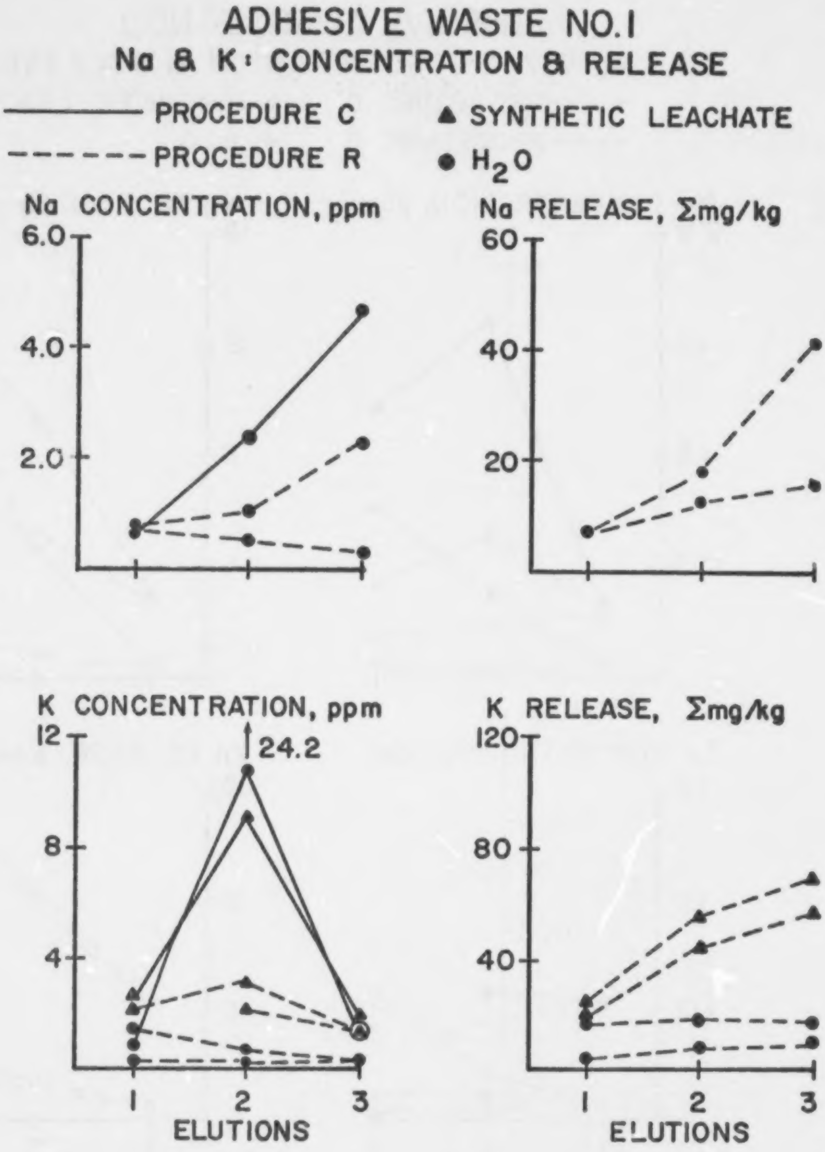


Figure 6. Na and K concentration and release curves for Adhesive Waste #1, SLT.

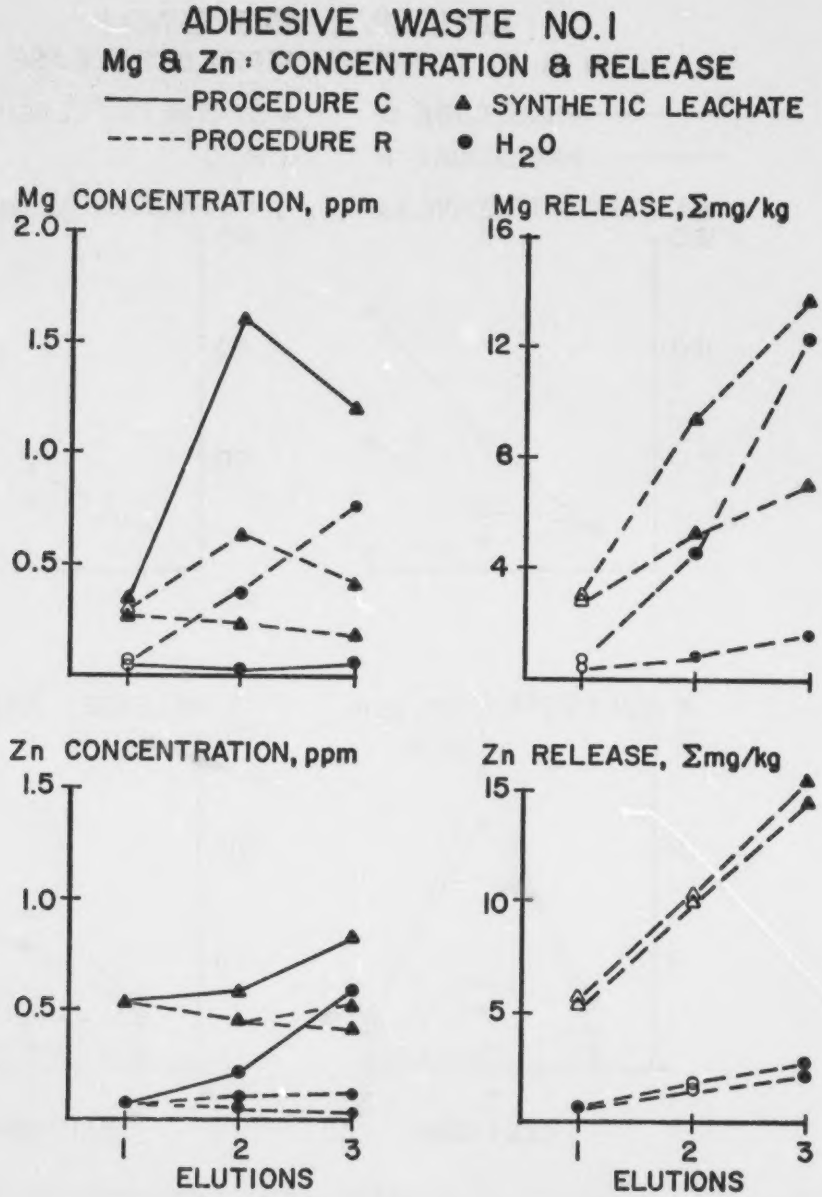


Figure 7. Mg and Zn concentration and release curves for Adhesive Waste #1, SLT.

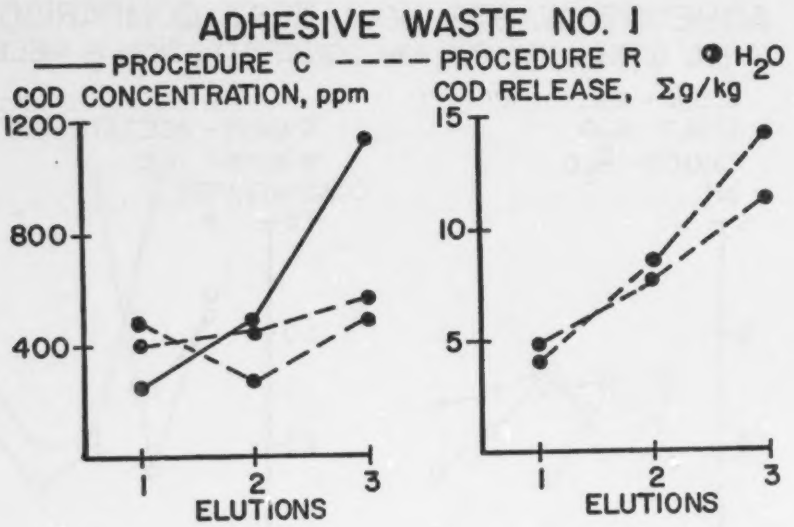


Figure 8. COD concentration and release curves for Adhesive Waste #1, SLT.

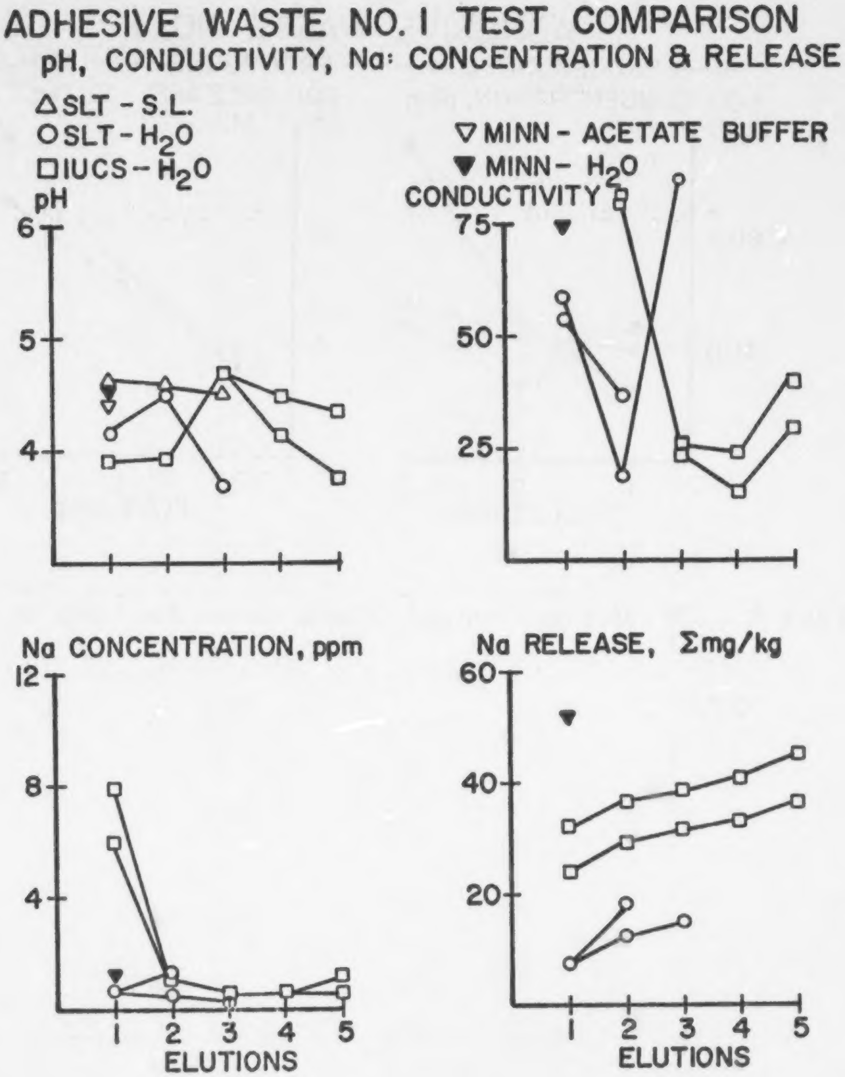


Figure 9. pH, specific conductance, and Na concentration and release curves for Adhesive Waste #1, test comparison.

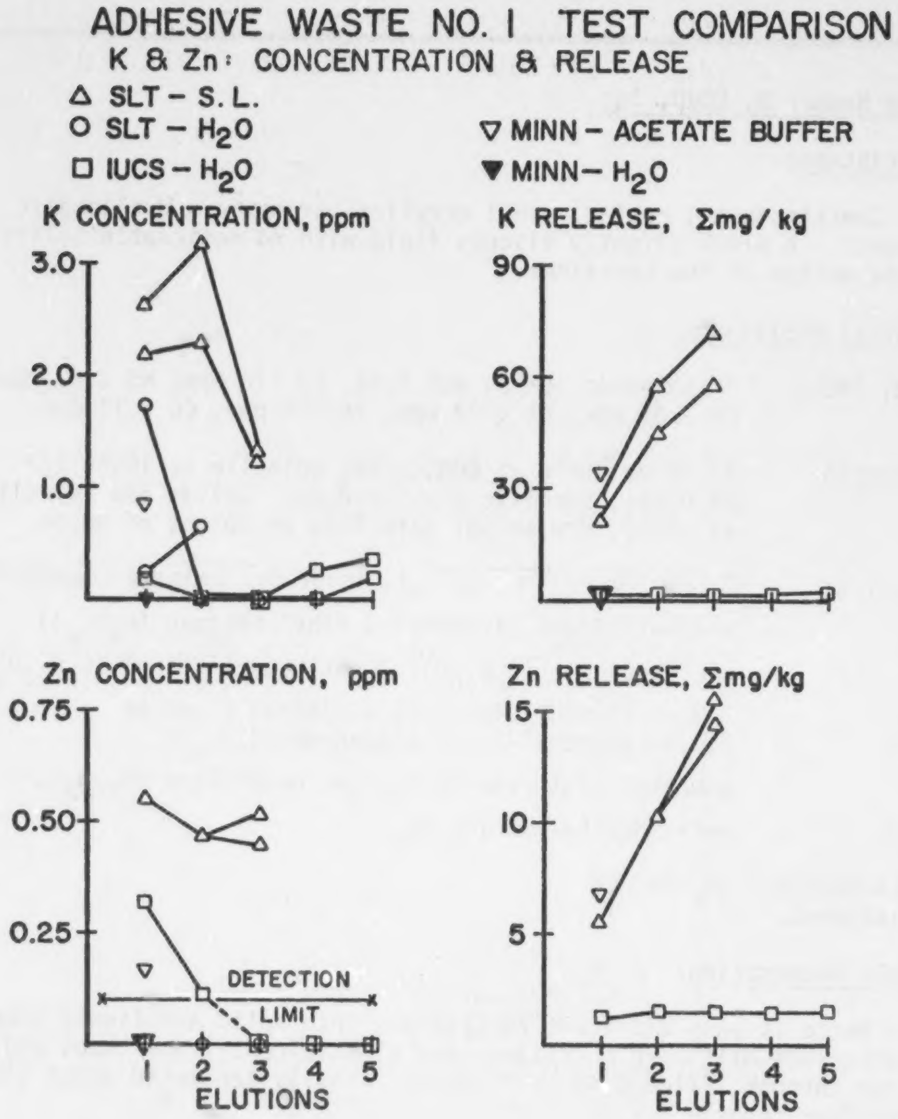


Figure 10. K and Zn concentration and release curves for Adhesive Waste #1, test comparison.

TABLE 19. INK AND PAINT WASTE (IPW): DESCRIPTION AND SUMMARY OF RESULTS

Waste Number 2, ECHO, Inc.

Description:

Contains alkyl resins, vinyl acrylics, aromatic and aliphatic solvents. A black slightly viscous fluid with no noticeable solids on the bottom of the container.

Chemical Analysis:

ECHO, INC:	flash point 100°C, ash 4.6%, Cd 110 ppm, Hg 0.02 ppm, Pb 0.51 ppm, Cr 0.12 ppm, Zn 190 ppm, Cu 0.11 ppm.
Wisconsin:	97.2% volatile at 600°C, 78% volatile at 105°C for 24 hours, specific gravity 0.88. Solids 49% volatile at 105°C, dry solids were 5.9% by weight of waste.
Organics:	Xylene (o,m, + p, C_8H_{10}), isopropyl benzene (cumene-C_9H_{12}), m-ethyltoluene (1-methyl-3 ethyl benzene (C_9H_{12})) cyclohexanone ($C_6H_{10}O$), 2-nor-butoxyethanol ($C_6H_{14}O_2$), 3,3,6-trimethylbicyclo(3.1.0)hexan-2-one or 3,5,5-trimethyl-2-cyclohexanone ($C_9H_{14}O$), Dimethyl glutarate ($C_7H_{12}O_4$), napthalene ($C_{10}H_8$), methylnapthalene ($C_{11}H_{10}$).
Trace Metals of Interest:	Zn, Pb, Cd

Sample Preparation:

Waste is very difficult to separate into solid and liquid components. It dissolves Millipore MF filters and plastic centrifuge tubes and so will not filter through Teflon 0.45 µm filters. Finally separated using glass centrifuge tubes.

Comments:

Due to difficulty in separating large quantities of waste, procedure C in the SLT, which requires a lot of waste, was not run. H_2O leachates in all tests were colored, either green or orange, depending on elution.

TABLE 19 (continued)

Maximum Concentration and Release

Concentration, mg/l

Acid leachates	Na	K	Mg	Fe	Zn	Pb	Cu	Cd
SLT procedure R, SL	--	24.5	23		36	4.2	.20	.28
Minn. Acetate	--	9	1.9	.46	38	10.2	.14	.11
H_2O leachates								
SLT procedure R	190	10	5.5	3.2	.27	0	.34	0
IUCS	455	30.5	18	.20	1.17	.24	1.15	0
Minn.	35	2.5	1.3	0	0	0	.09	0

Release, mg/kg

Acid leachates	Na	K	Mg	Fe	Zn	Pb	Cu	Cd
SLT procedure R, SL		505	292		681	85.5	3.8	4.2
Minn. Acetate		360	72	18.4	1520	406	5.6	4.4
H_2O leachates								
SLT procedure R	2410	169	83	34	2.7	0	3.9	0
IUCS	2862	274	137	1.8	5.8	0	5.3	0
Minn.	1400	100	52	0	0	0	0	0

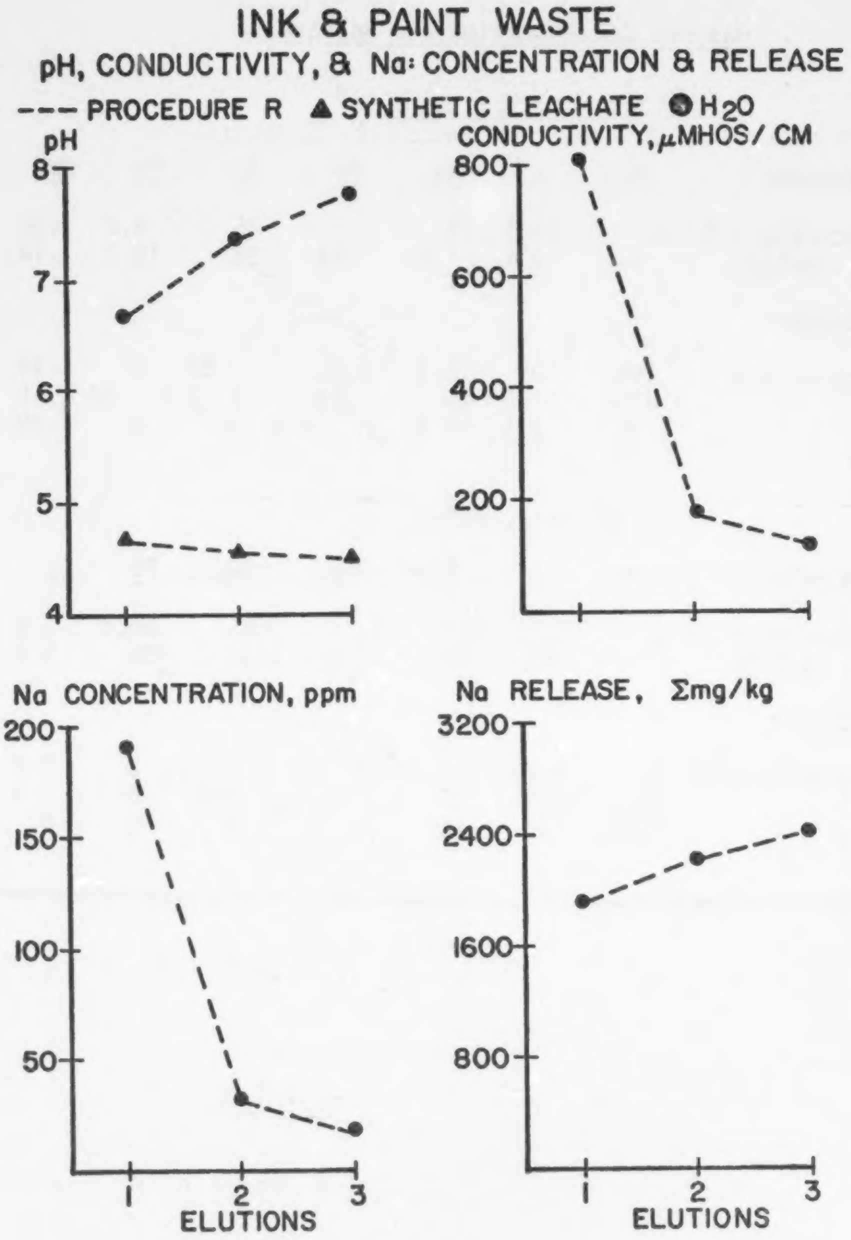


Figure 11. pH, specific conductance, and Na concentration and release curves for Ink and Paint Waste, SLT.

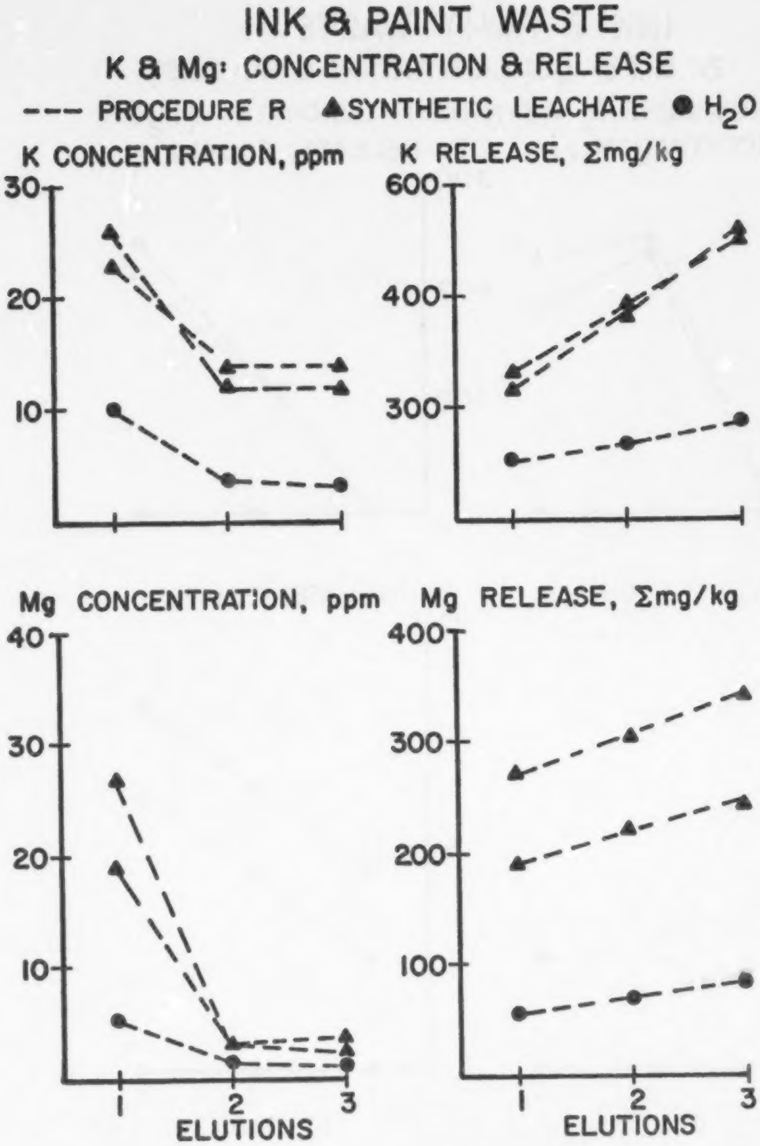


Figure 12. K and Mg concentration and release curves for Ink and Paint Waste, SLT.

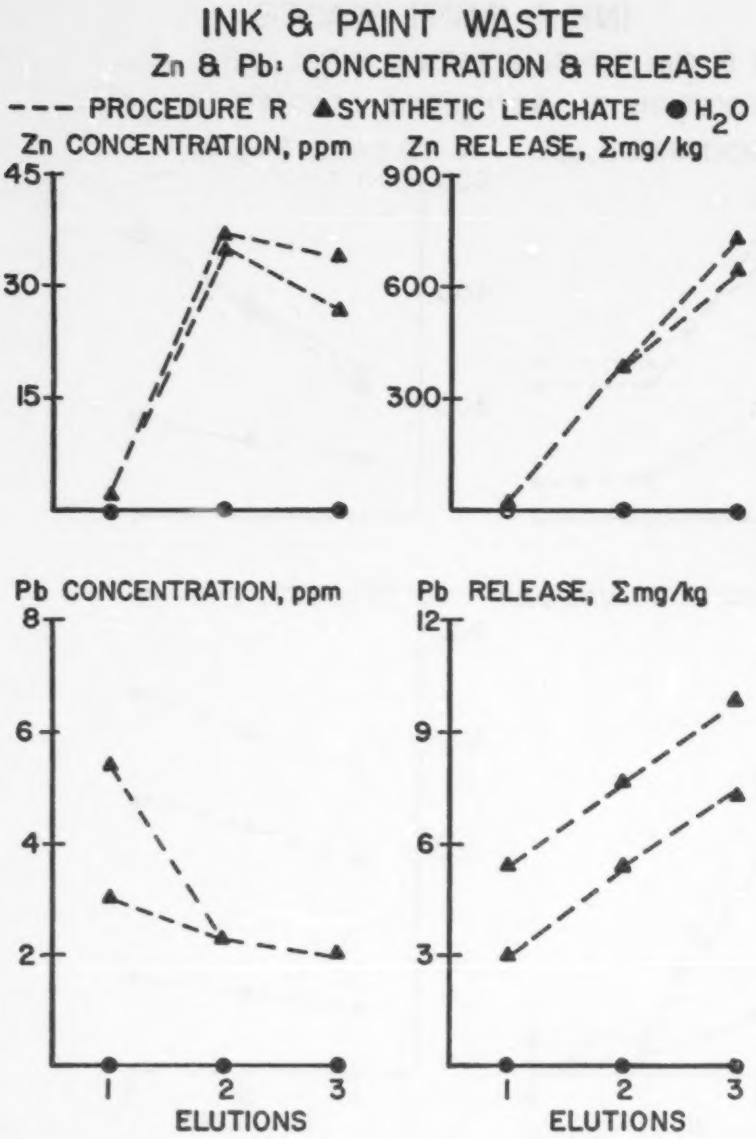


Figure 13. Zn and Pb concentration and release curves for Ink and Paint Waste, SLT.

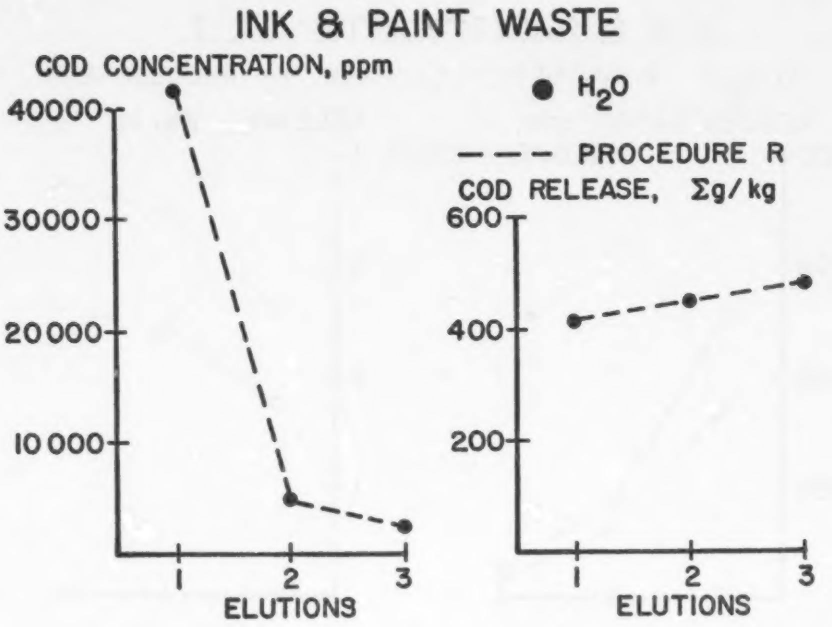


Figure 14. COD concentration and release curves for Ink and Paint Waste, SLT.

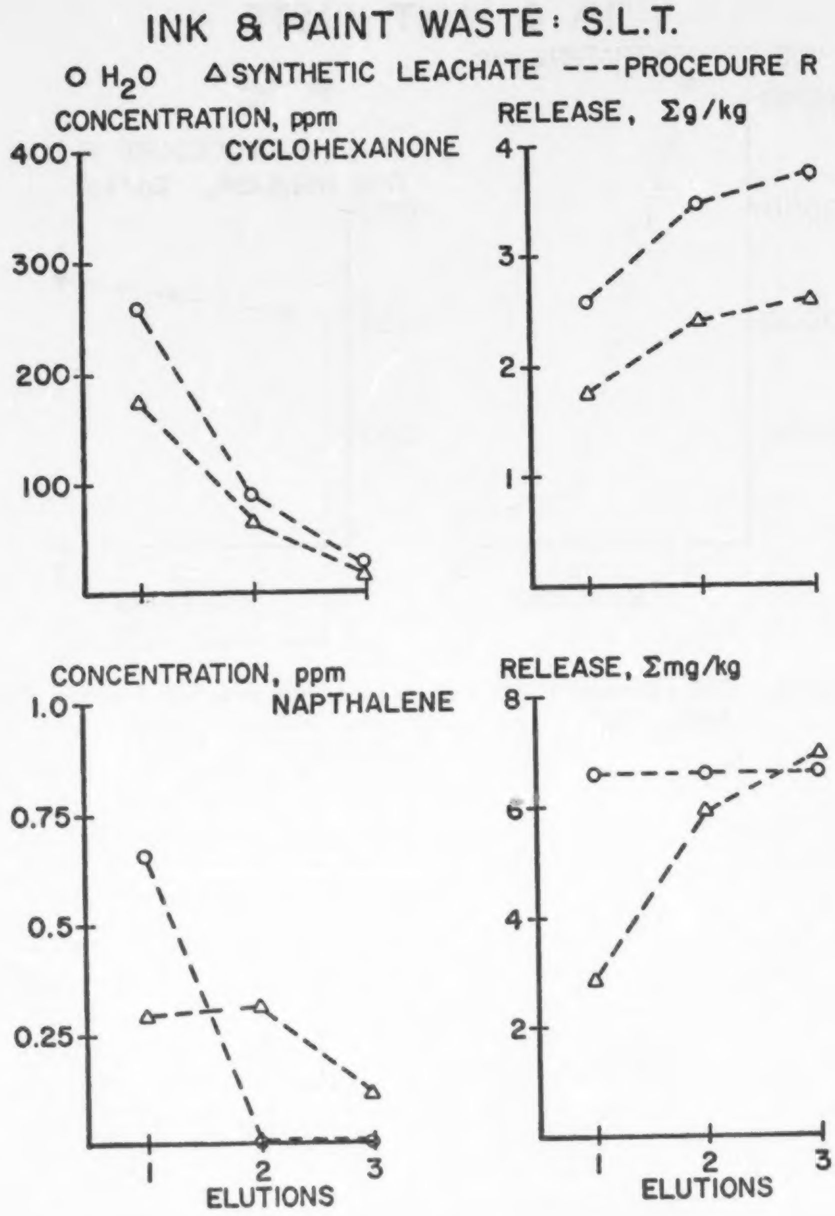


Figure 15. Cyclohexanone and Napthalene concentration and release curves for Ink and Paint Waste, SLT.

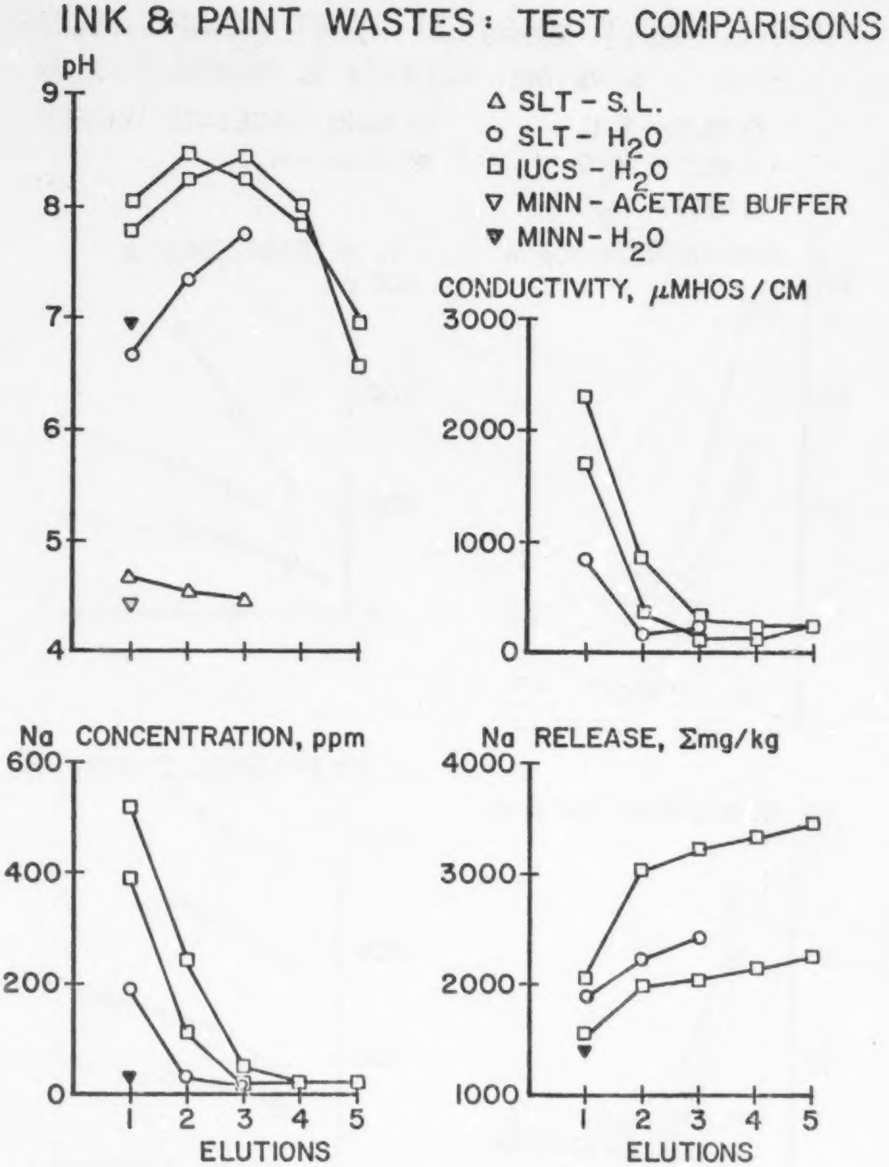


Figure 16. pH, specific conductance and Na concentration and release curves for Ink and Paint Waste, test comparison.

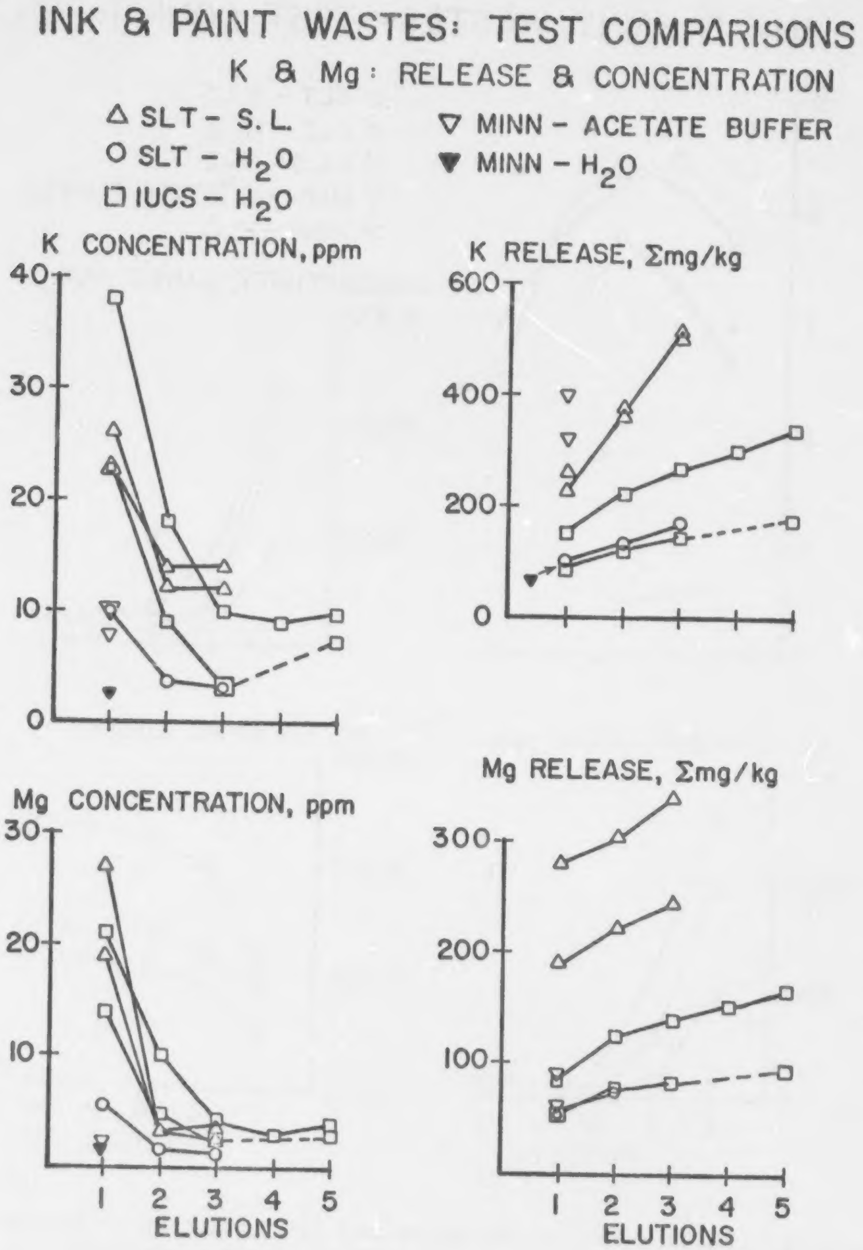


Figure 17. K and Mg concentration and release curves for Ink and Paint Waste, test comparison.

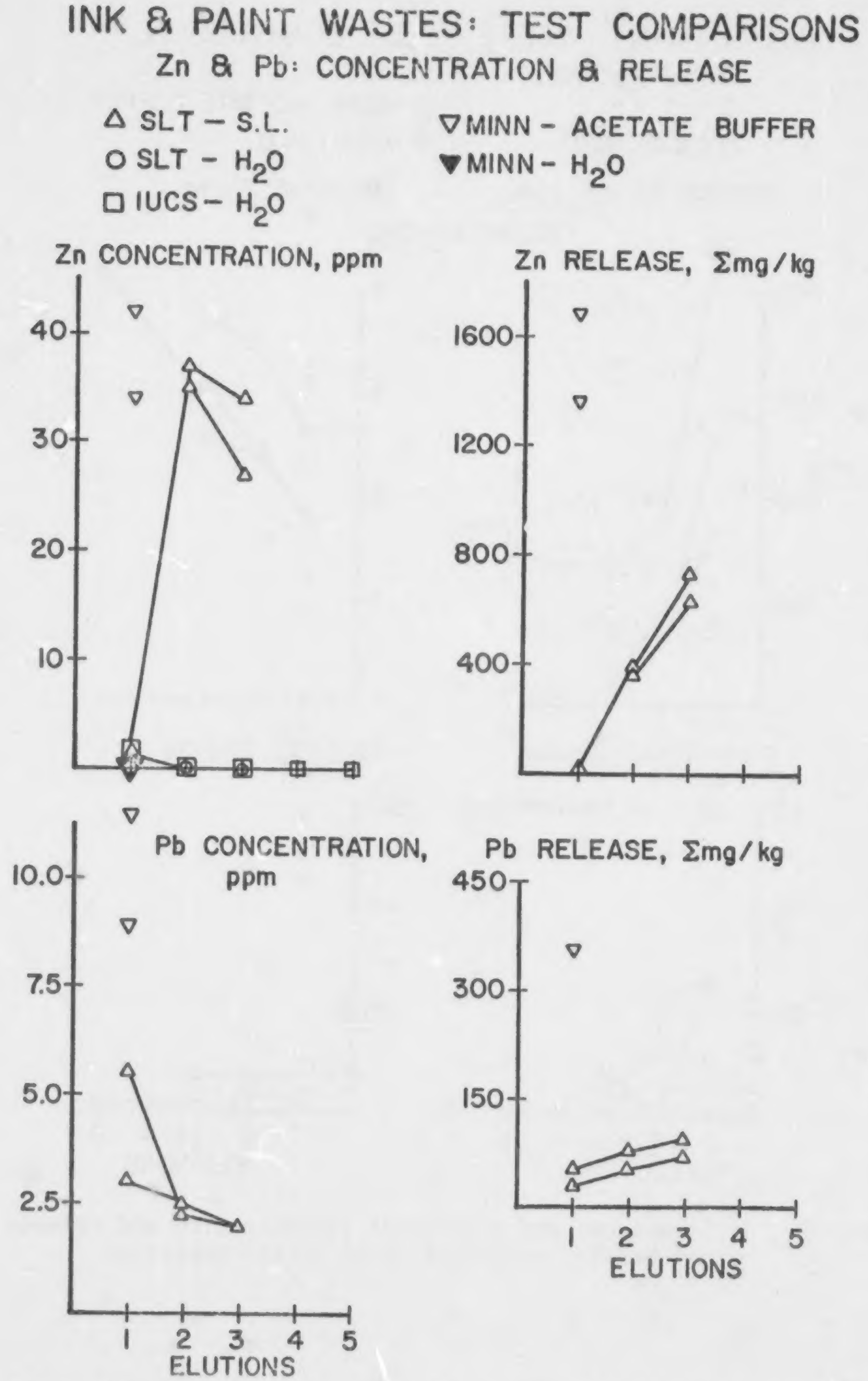


Figure 18. Zn and Pb concentration and release curves for Ink and Paint Waste, test comparison.

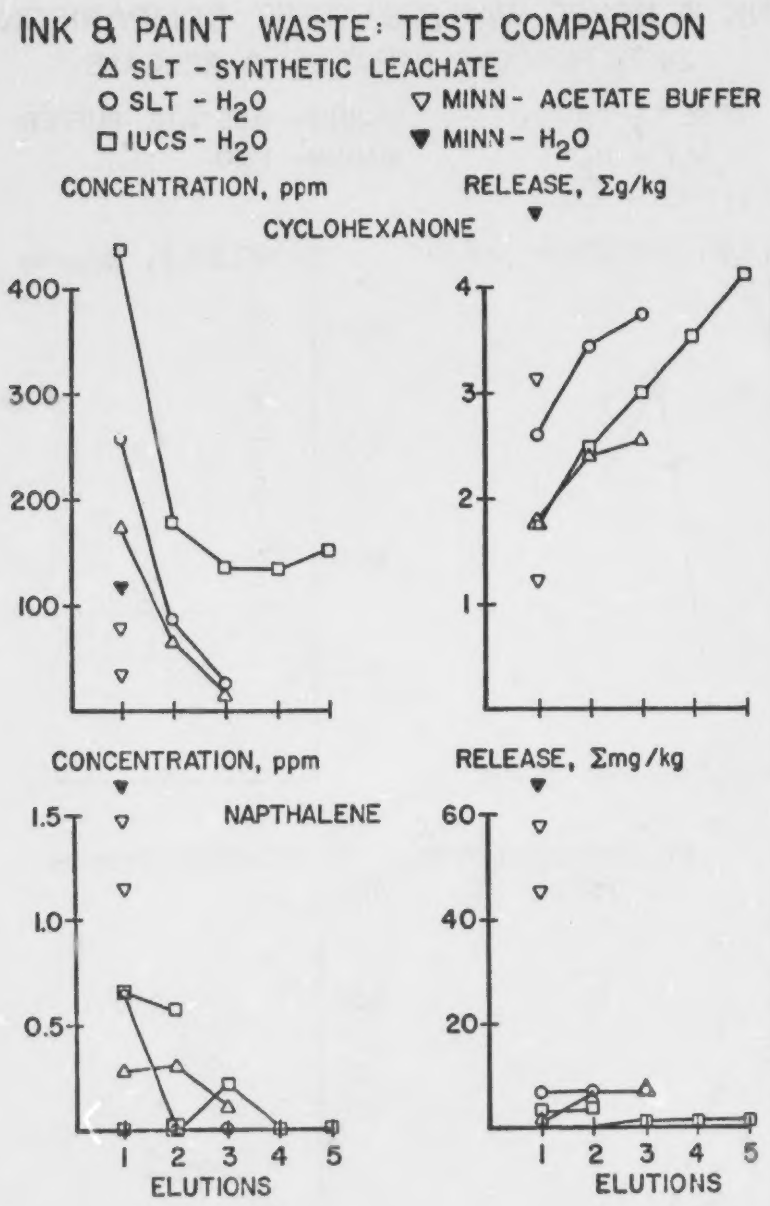
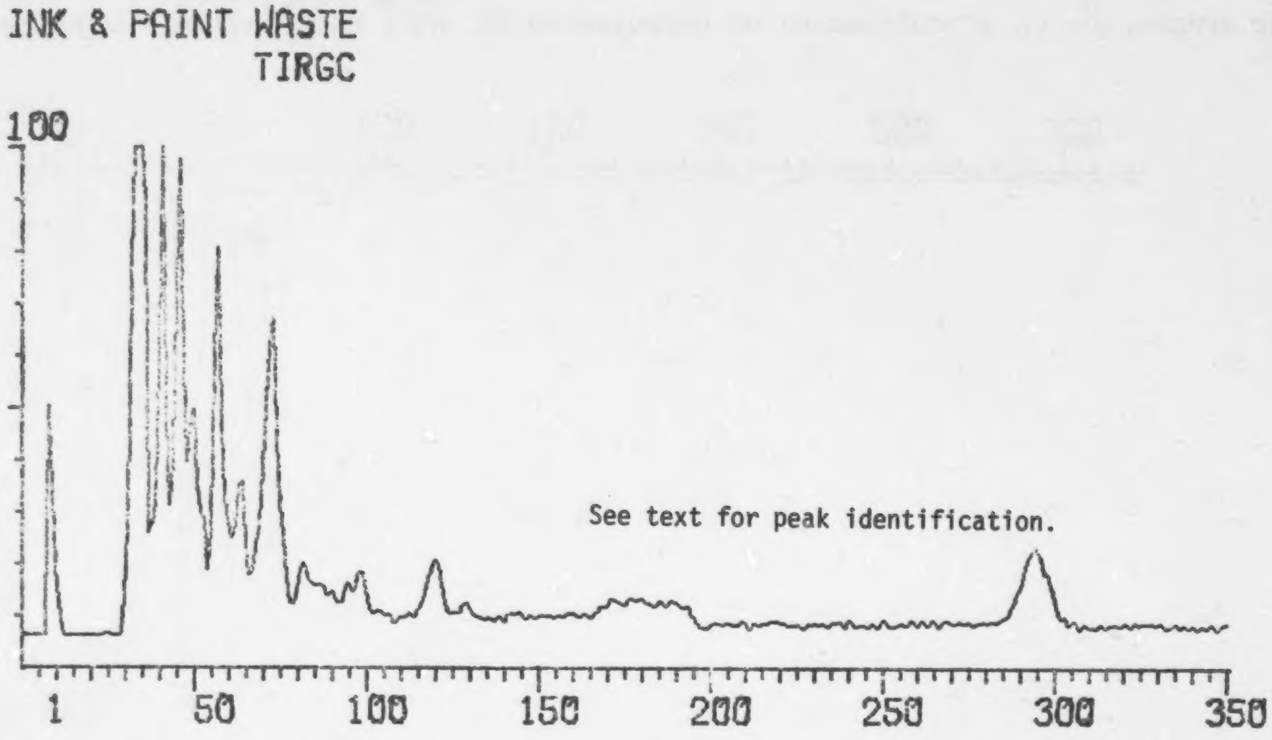


Figure 19. Cyclohexanone and Napthalene concentration and release curves for Ink and Paint Waste, test comparison.



See text for peak identification.

Figure 20. Total ion reconstructed gas chromatogram of Ink and Paint Waste,

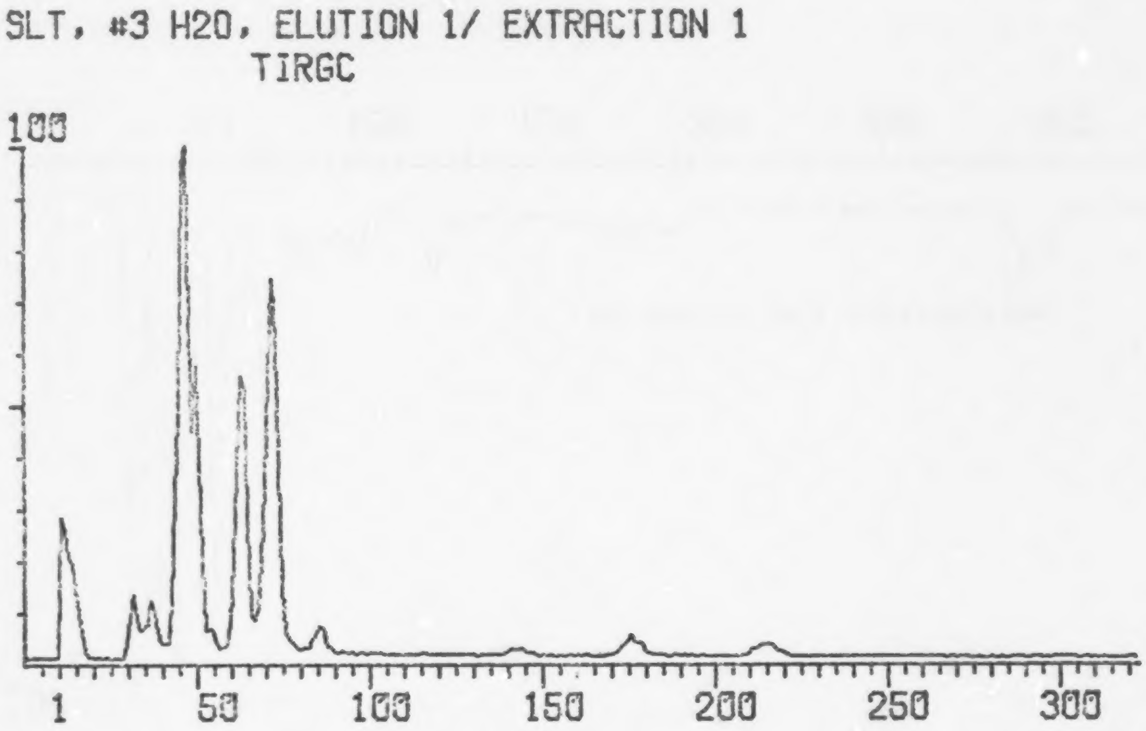


Figure 21. Representative total ion reconstructed gas chromatogram of SLT H_2O leachate of Ink and Paint Waste.

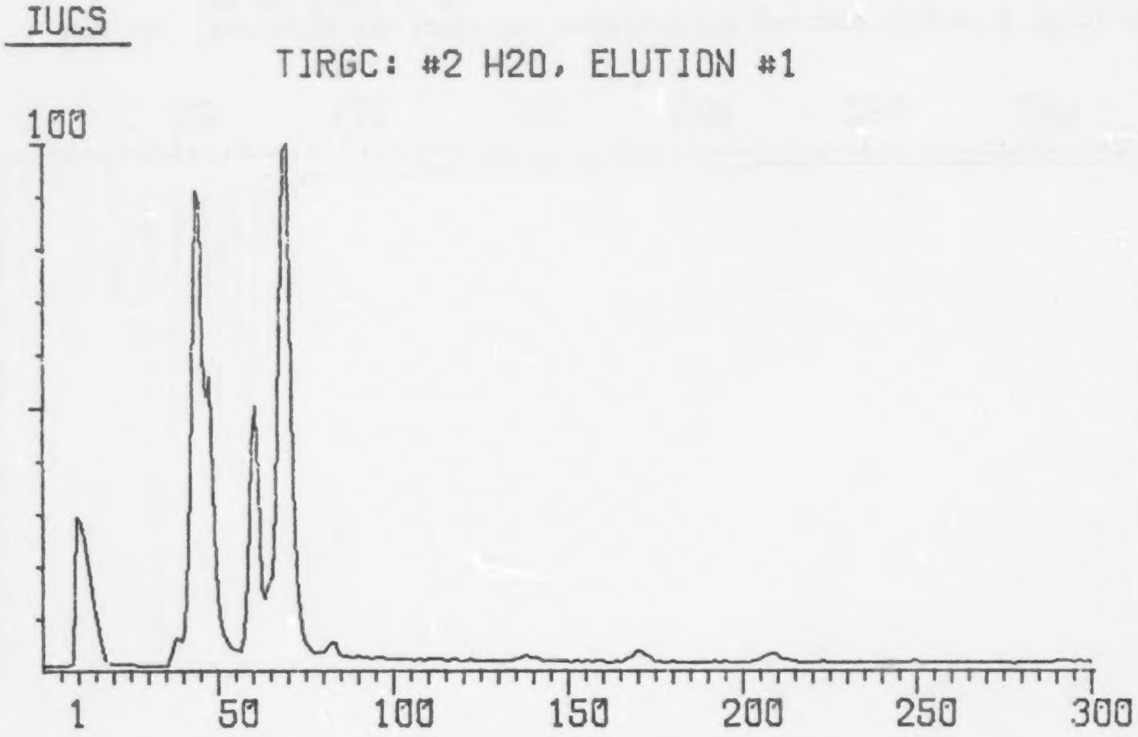


Figure 22. Representative total ion reconstructed gas chromatogram of IUCS test H_2O leachate of Ink and Paint Waste.

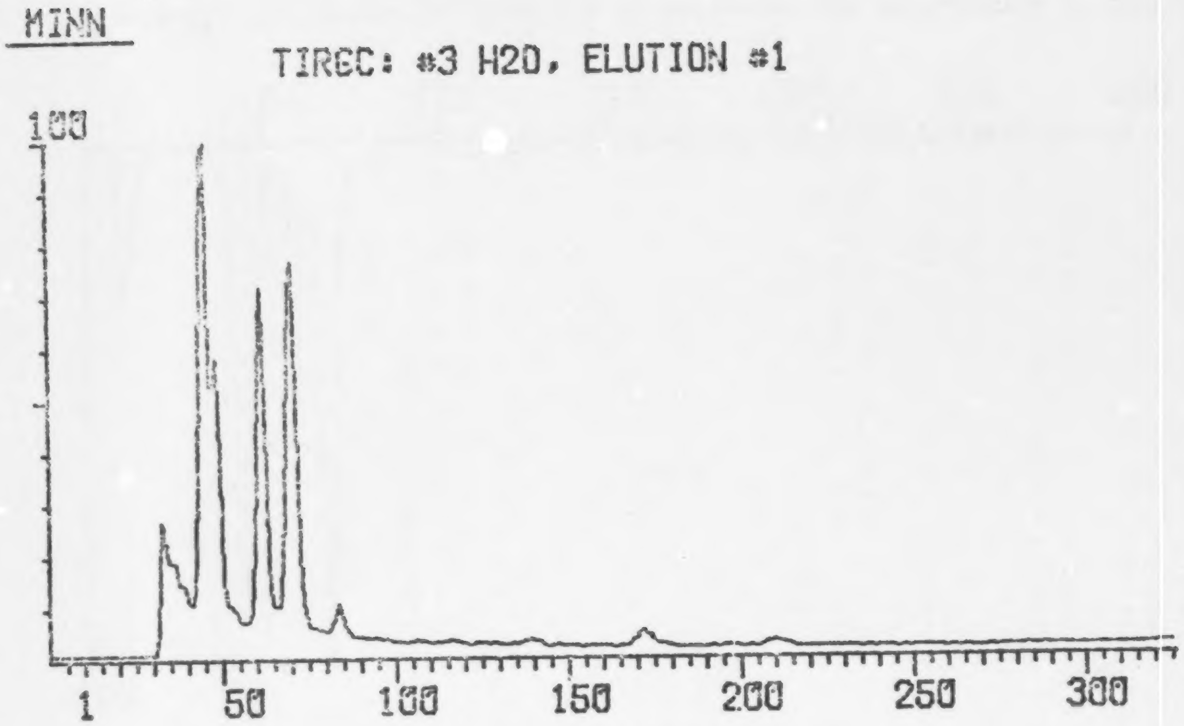


Figure 23. Representative total ion reconstructed gas chromatogram of Minn. test H_2O leachate from Ink and Paint Waste.

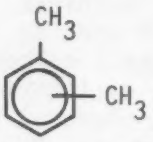
Discussion

The inorganic parameters are not of great interest. Pb and Zn were released in acid leaching solutions but not in H_2O leachates, and both were released in higher concentrations in the Minnesota leachates than in the SLT leachates.

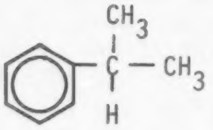
The organic parameters are of interest and were thoroughly investigated. COD in the SLT H_2O leachates shows that very large amounts of organic compounds were being released. The H_2O leachates in all tests were colored—the first day the color was a combination of green and orange, while on subsequent elutions the color was orange. The relatively low conductivity indicates that nonionic compounds were being released.

Extensive gas chromatograph—mass spectrometry analysis of both the waste hexane extract and the leachates was done.

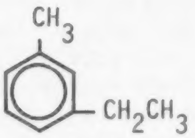
The waste hexane extract showed that the waste contained at least six aromatic ring compounds with alkyl side chains. These elute in the total ion reconstructed gas chromatogram (TIRGC) at peaks numbered 42, 47, 59, 104, 126, and 135 (see Figure 20). Three were identified as xylene (peak number 42), isopropylbenzene (also called cumene, peak number 47), and m-ethyltoluene (peak number 59). The structures for these compounds are given below.



(xylene,o,m, p)

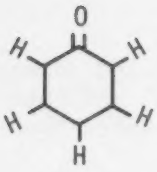


isopropyl benzene



m-ethyltoluene
(1-methyl-3-ethyl benzene)

The other aromatic compounds with alkyl side chains could not be further characterized. Five other compounds were positively identified in the waste. Their structures and peak numbers are given in the following drawings:



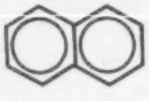
cyclohexanone
peak No. 66

$C_4H_9{}^nOCH_2CH_2OH$

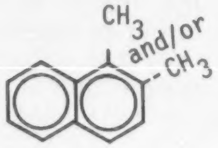
2-nor-butoxyethanol
peak No. 76

$CH_3O_2C(CH_2)_3CO_2CH_3$

Dimethyl glutarate
peak No. 229



napthalene
peak No. 309



methylnapthalene (α and/or β)
peak No. 450

In addition, peak number 188 was identified as either 3,3,6-trimethyl bicyclo (3.1.0.) hexan-2-one or 3,5,5-trimethyl-2-cyclohexanone.

Six of the identified compounds were analyzed in the leachate extracts. The three identified aromatic compounds with alkyl side chains were found to not elute in any of the test procedures or with any leaching solution. The substance in peak 188 was found to elute in leachates from all tests in significant concentrations. No standards of either compound were available, so neither positive identification nor quantification could be made.

Cyclohexanone and napthalene were quantified in the leachates. The release patterns of both compounds are given in Figures 15 and 19. Cyclohexanone is released in high concentrations, with the highest concentrations coming in the first elution. In the IUCS test, the cyclohexanone reached a constant concentration after the first elution, whereas, in the SLT the concentration decreased with each elution. In both the SLT and the Minnesota tests, the H_2O leachates had higher cyclohexanone concentrations than the acid leachates. Napthalene was released in low concentrations in a pattern that is very difficult to interpret. The Minnesota test had the highest napthalene concentrations and release.

The high COD concentrations leached from the waste and the comparatively small amounts of materials identified indicate that much of the leached organic material was not identified. The use of a relatively nonpolar solvent for extracting the waste or leachate emphasizes the analysis of compounds of lower polarity. Noting the lack of aromatic compounds with side chains in the leachates, it is apparent that the high organic leaching from the waste, as indicated by the high COD concentrations, does not cause solubilization of these nonpolar compounds. The high COD concentrations should be of concern when considering landfilling of this waste.

The use of GC-MS for analysis of unidentified or unclassified organic compounds is not recommended for routine use in a standard test. GC-MS analyses require highly trained personnel and considerable time. The identification of a specific compound in a waste when the identity or general classification of the compound is not known is very difficult and time consuming. Note that Figures A-1 through A-9 present additional GC-MS results.

TABLE 20. COAL TAR SLUDGE: DESCRIPTION AND SUMMARY OF RESULTS

Waste Number 3, ECHO, Inc.

Physical Description: Thick, viscous tar floating on water layer.

Chemical Description:

ECHO	- BTU - 14000/lb, flash point 98°C, Ash 2.7%, Cd 1.15 ppm, Pb 29.9 ppm, Cr 51.5 ppm, Zn 107 ppm, Cu 9.7 ppm.
Wisconsin (solid)	- 62% volatile at 600°C 29% volatile at 105°C, 24 hours
Organics	- phenol, cresol, napthalene and quinoline identified in leachate
Trace Metals of Interest	- Cu, Zn, Cr, Pb

Sample Preparation:

Floating tar sampled directly. Homogenization of water and tar layers would have been impossible given consistency of tar. Tar difficult to clean.

(continued)

TABLE 20 (continued)

Maximum Concentration and Release

Concentration, mg/l

Acid leachates	Na	K	Mg	Zn	COD	Napt.	Phenol	Cresol	Quinoline
SLT proc. C, SL		54	1.4	.50		12.7	493	138	307
SLT proc. R, SL		9.3	.56	.42		21.9	96	58.5	93.5
Minn. Acet.		.94	.15	.12		2.8	2.6	1.4	0

H_2O leachates	Na	K	Mg	Zn	COD	Napt.	Phenol	Cresol	Quinoline
SLT proc. C	8.10	4.1	1.6	0	2250	20.1	193	80.2	64.0
SLT proc. R	4.0	1.9	.65	0	730	20.9	112	58.1	62.0
IUCS	0.49	.40	.59	0		5.7	67.9	36.5	26
Minn.	1.2	.14	.17	0		2.4	2.7	1.3	0

Release, mg/kg

Acid leachates	Na	K	Mg	Zn	COD	Napt.	Phenol	Cresol	Quinoline
SLT proc. R, SL		167	10.9	11.0		624	1644	1290	2176
		37.6	6	4.8		112	104	56	0

H_2O leachates	Na	K	Mg	Zn	COD	Napt.	Phenol	Cresol	Quinoline
SLT proc. R	59	25.5	11	0	15390	578	1949	1338	1726
IUCS	7.5	2.9	3.7	0	4492	81.2	472	288	333
Minn.	48	5.6	6.8	0	4560	96	108	52	0

Cu, Cr, Zn and Pb were below detection.

Note that the Napthalene and Quinoline concentration and release test comparison curves were presented earlier as Figure 3.

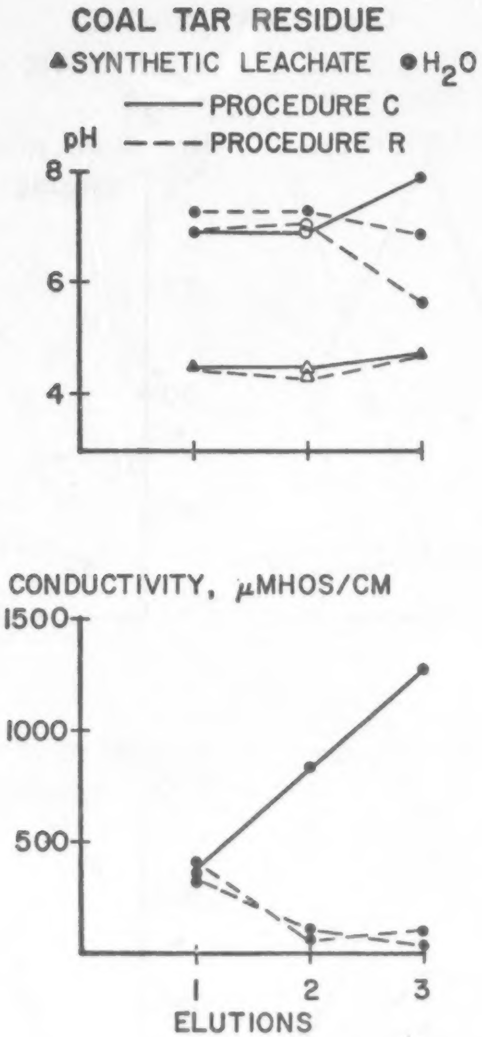


Figure 24. pH and specific conductance curves for Coal Tar Waste, SLT.

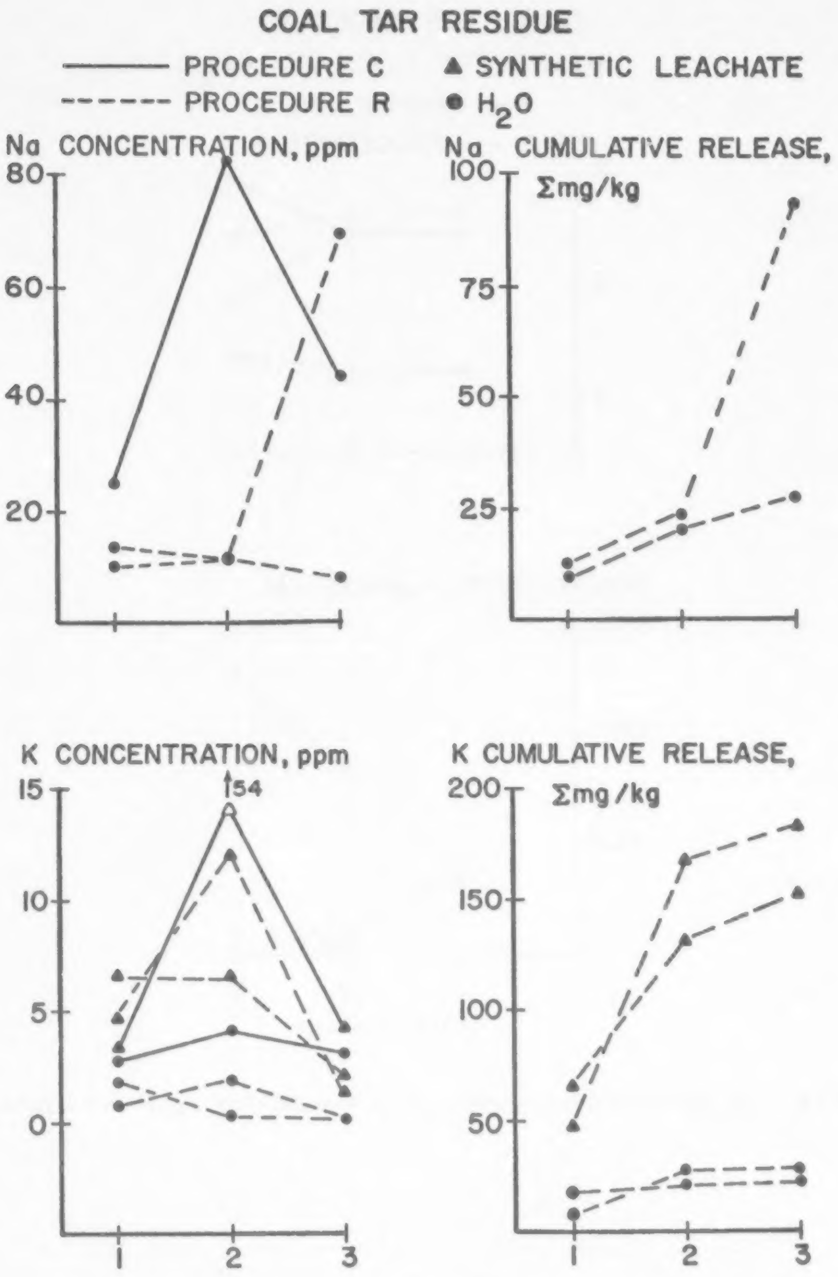


Figure 25. Na and K concentration and release curves for Coal Tar Waste, SLT.

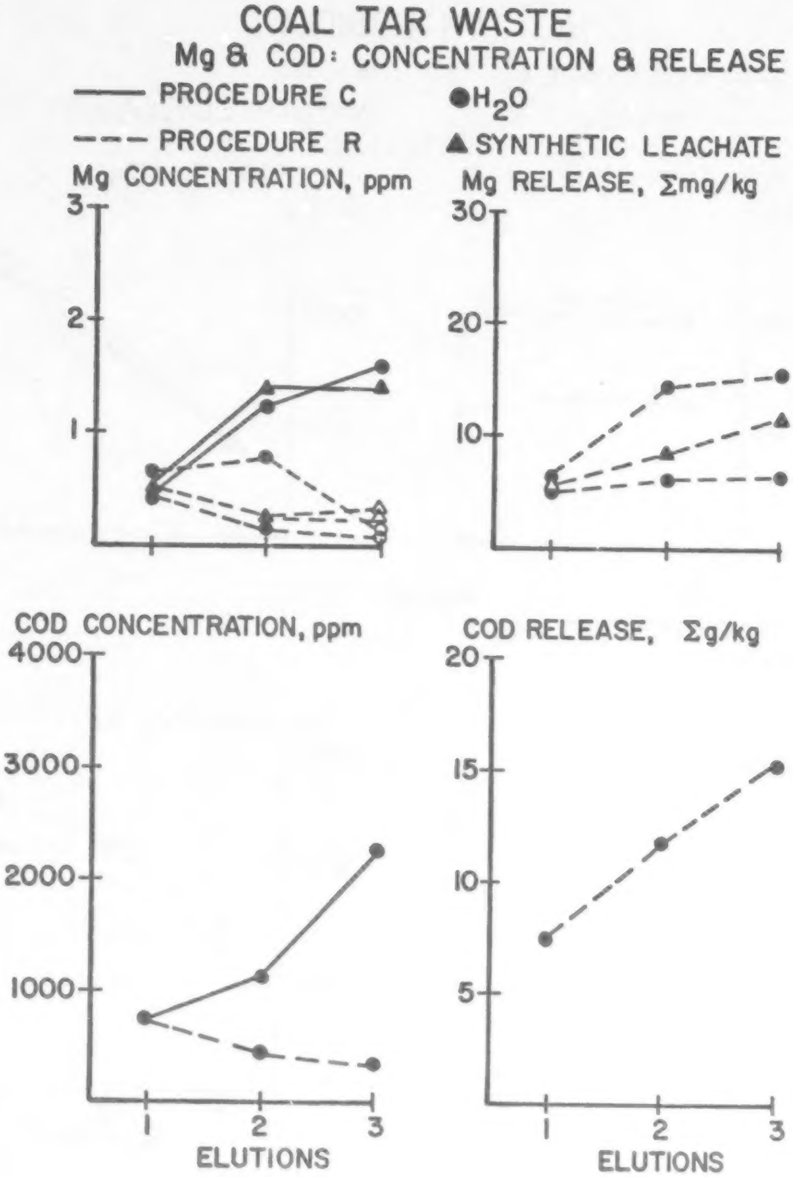


Figure 26. Mg and COD concentration and release curves for Coal Tar Waste, SLT.

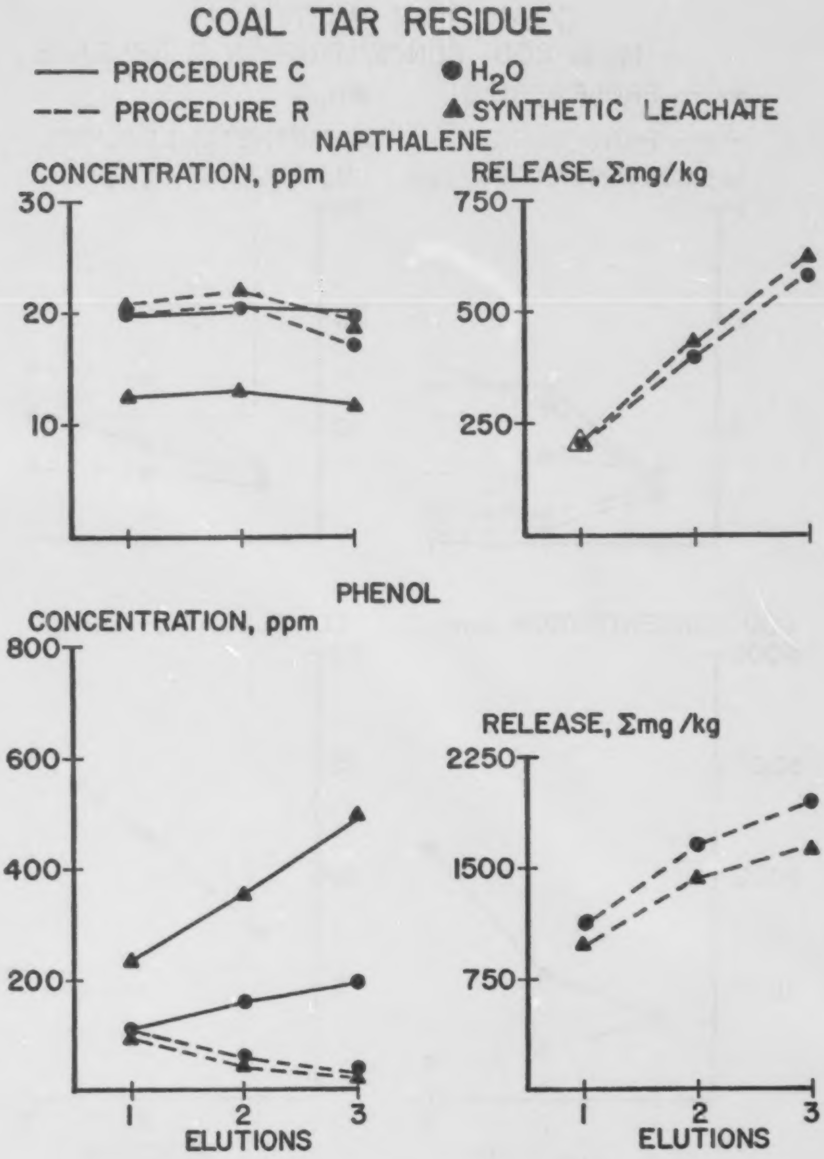


Figure 27. Napthalene and Phenol concentration and release curves for Coal Tar Waste, SLT.

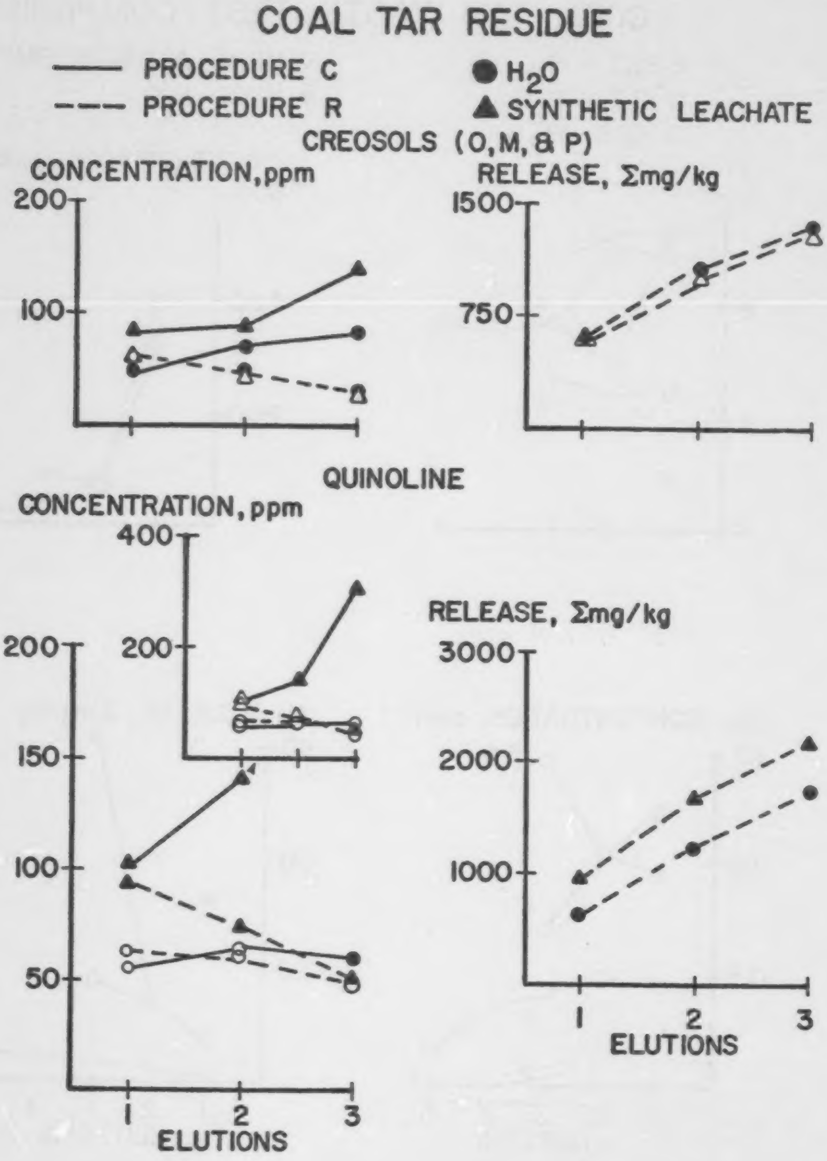


Figure 28. Creosols and Quinoline concentration and release curves for Coal Tar Waste, SLT.

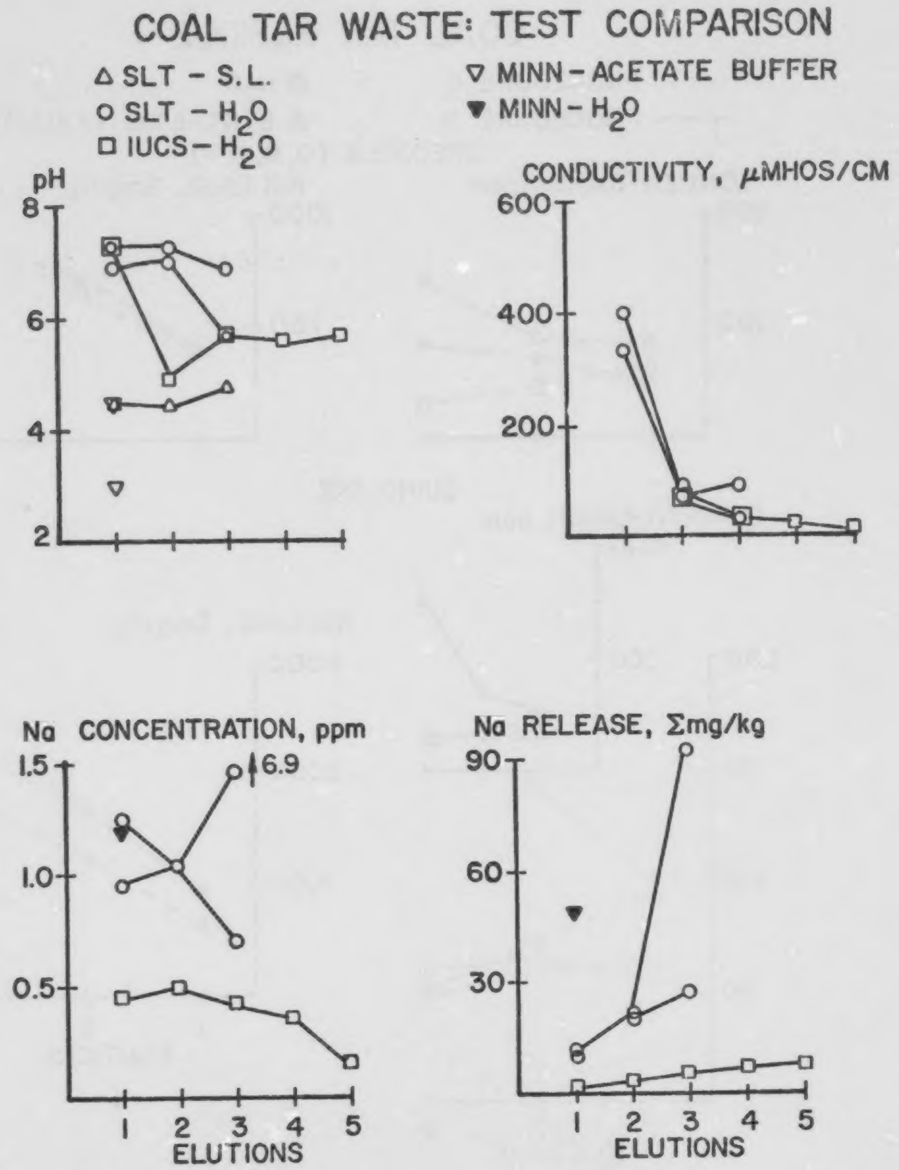


Figure 29. pH, specific conductance, and Na concentration and release curves for Coal Tar Waste, test comparison.

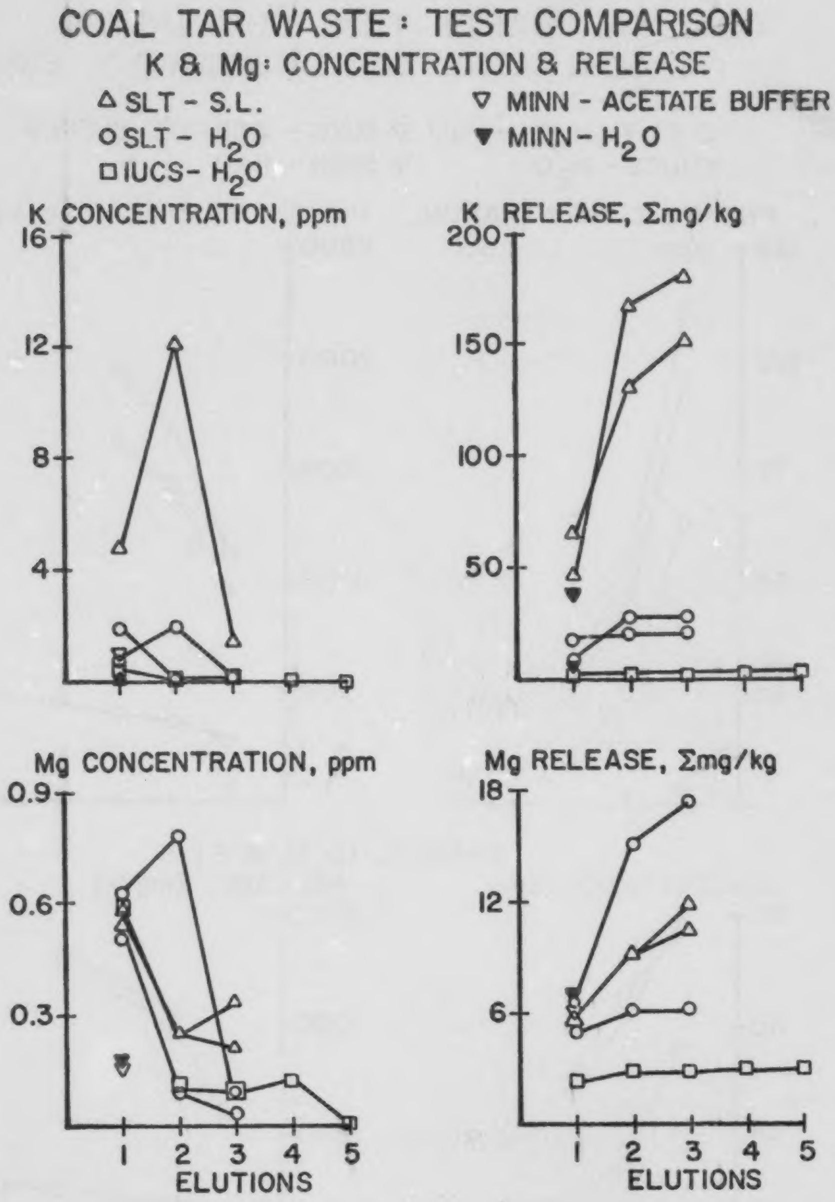


Figure 30. K and Mg concentration and release curves for Coal Tar Waste, test comparison.

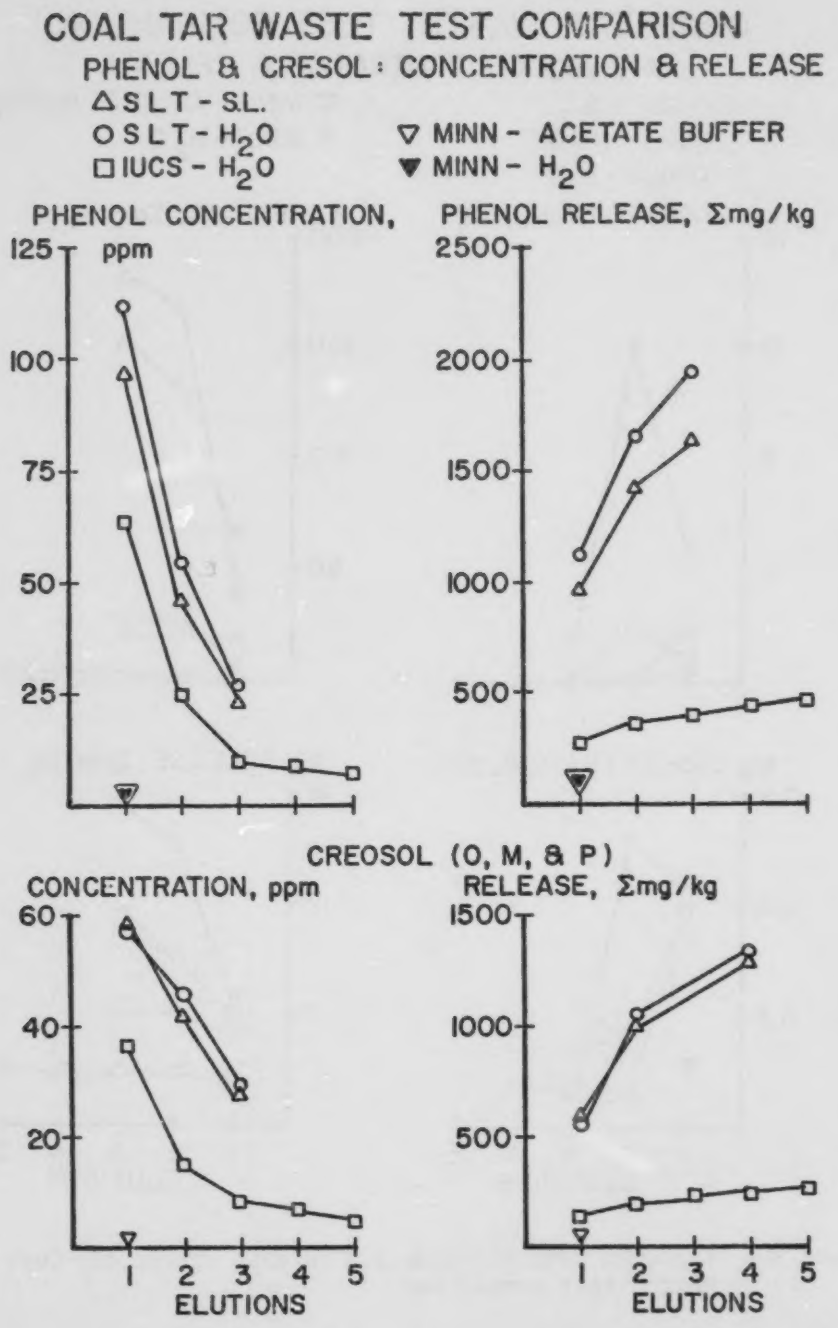


Figure 31. Phenol and Creosol concentration and release curves for Coal Tar Waste, test comparison.

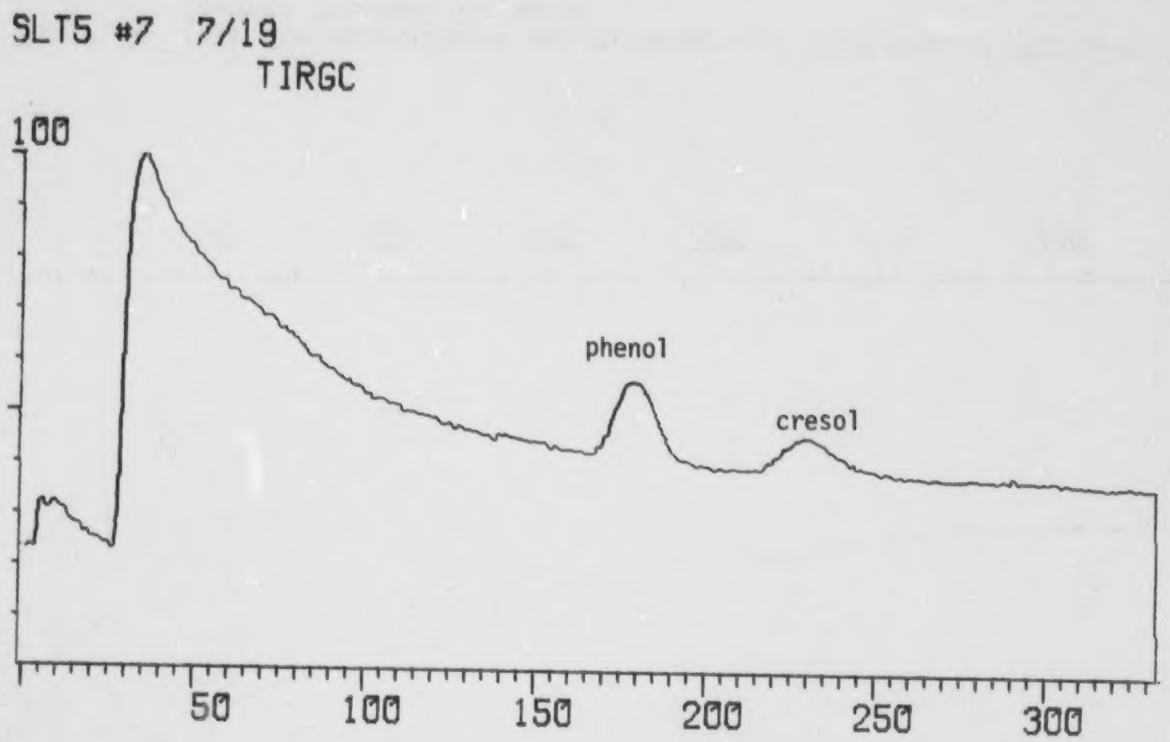


Figure 32. Total ion reconstructed gas chromatogram of distillate of SLT H_2O leachate from Coal Tar Waste.

(Quinoline and Napthalene cannot be seen on the TIRGC, but can be quantified using mass spectra.)

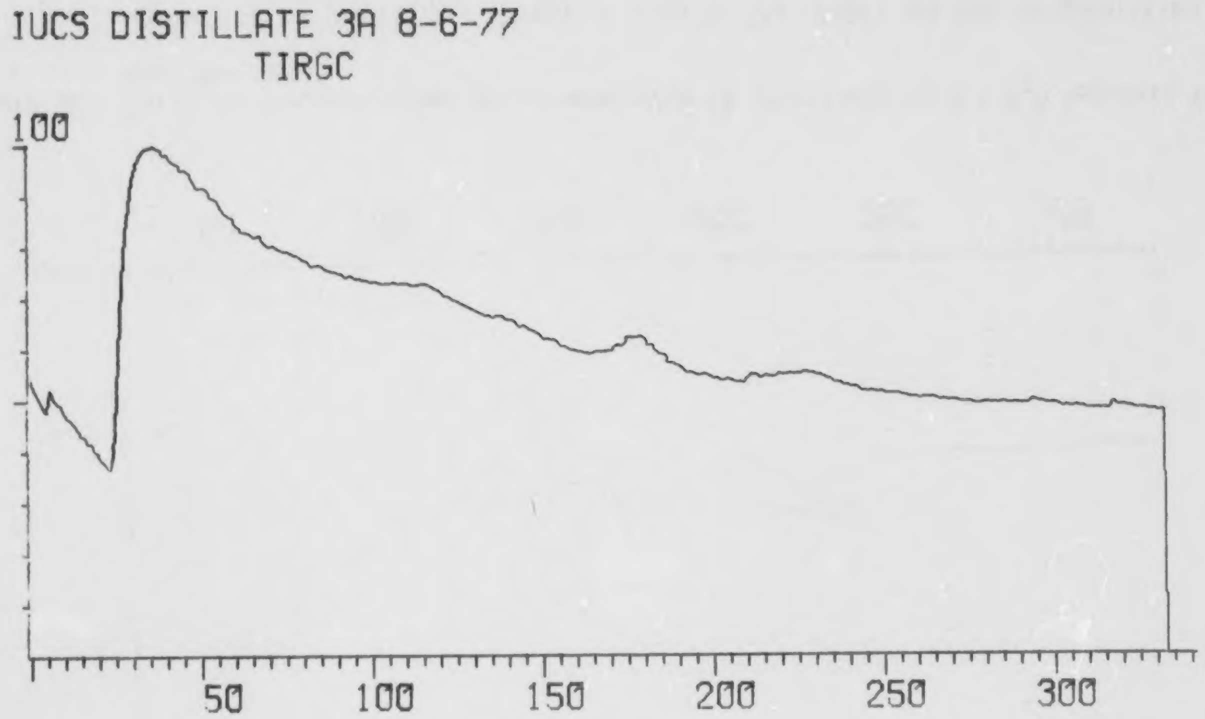


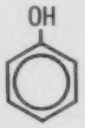
Figure 33. Total ion reconstructed gas chromatogram of distillate of IUCS test H_2O leachate from Coal Tar Waste.

Discussion

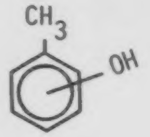
The waste's physical composition, much like road tar, seems to be an important factor in controlling the leaching test results.

The inorganic parameters are not of much interest. Na, K, Mg, and Zn are leached in low concentrations, while Cu is below detection.

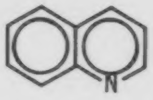
Organic parameters are of interest. Phenols and cresols (ortho, meta and para) were presumed to be present due to their common occurrence in coal tar wastes, and so test leachates were analyzed for these compounds. The leachates were distilled using the distillation procedure given in Standard Methods (3), then analyzed on a GC-MS. Napthalene and quinoline were also found in the distillates. The structures for these compounds are given below:



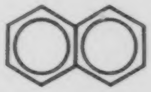
phenol



cresol



quinoline



napthalene

Phenol and cresol are both polar compounds due to the OH group. Quinoline is slightly polar and napthalene nonpolar. Phenol and cresol show similar behavior—increasing concentrations in both SL and H_2O leachates using procedure C and decreasing concentrations in procedure R. From the concentrations in procedure C leachates, it is apparent that the solutions are not saturated with either phenol or cresol at the end of the test, while the decreasing concentrations in procedure R show that the waste has not been completely depleted of either component. Napthalene, on the other hand, behaves as if it were saturated in both SL and H_2O leachates. The napthalene concentrations in both leachates maintains steady values throughout the test. The similarity in napthalene concentration in the SL and H_2O leachates show that the leachate composition does not have a great effect on solubilizing naphthalene.

Quinoline, on the other hand, shows different leaching patterns in SL and H_2O leaching solutions. The H_2O leachates have constant concentrations, indicating saturation, while the SL leachates have a rising concentration in procedure C leachates and a falling concentration in procedure R.

Quinoline is a base ($K_b = 3 \times 10^{-10}$) and should be more soluble in acid solutions than in neutral or basic solutions. Quinoline concentrations in the SL and H_2O leachates from procedure C of the SLT shows the differing solubilities quite well. In SL samples, the quinoline concentration rises in each procedure C elution, suggesting that the amount of quinoline available for leaching controlled the concentration, and that quinoline was not near saturation. In the H_2O leachates, on the other hand, the quinoline behaves as if it were saturated, i.e., the concentration is constant in procedure C leachate. At the pH of the SL (4.5), much of the quinoline (Q) should be protonated (i.e., be in the form HQ^+) and should be more soluble than the unprotonated quinoline. At the pH of the H_2O leachates (7), quinoline should be predominately unprotonated. In short, at a pH of about 7, quinoline (in an unprotonated form) appears to be saturated in the SLT H_2O leachates at a concentration of around 60 mg/l, while in the acid SL, quinoline (in a protonated form) appears to be unsaturated at concentrations over 300 mg/l.

TABLE 21. HEALTH AND BEAUTY CARE WASTE (HBC):
DESCRIPTION AND SUMMARY OF RESULTS

(Including Latex from Paint Manufacture and Some Basic
Chemical Salt Wash Water)

Waste Number 4, ECHO, Inc.	
Physical Description:	slightly viscous emulsion, black, some noticeable solids.
Chemical Analysis:	
ECHO	pH-5.9, sus. solids-1%, Ash 6.1%, Cd.07 ppm, Hg .02 ppm, Pb 1.1 ppm, Cr .40 ppm, Zn 18 ppm, Cu 2.8 ppm.
Wisconsin	99.2% volatile at 600°C 27% volatile at 105°C for 24 hours specific gravity, 0.85
Organics	None specified.
Trace Metal of Interest	Pb, Zn, Cu
Sample Preparation:	separates with centrifugation solids - 38.9% volatile at 105°C, 24 hours solids (dry weight) compose 2.8% of waste

(continued)

TABLE 21 (continued)

Maximum Concentration and Release

Concentration, mg/l

Acid leachates	Na	K	Mg	Zn	Cd	Fe	Cu	Pb	COD
SLT proc. C, SL		182	32	25.0	.92		5.60	0.86	
SLT proc. R, SL		67	12.2	12.8	.39		1.55	0.69	
Minn. Acet.		1.7	2.6	2.9		52	9.6	.40	
H_2O leachates									
SLT proc. C	630	88	18	11.0		122	14.0	0	93,600
SLT proc. R	294	48.9	8.70	5.9	.14	37.0	5.9	0	12,760
IUCS	570	84	18.4	11.5		81.0	10	0	33,600
Minn.	58	1.1	1.8	1.4		11	1.5	0	

Release, mg/kg

Acid leachates	Na	K	Mg	Zn	Cd	Fe	Cu	Pb	COD
SLT proc. R, SL		921	154	174	6.0		38	18.8	
Minn. Acet.		68	104	116		2080	384	16	
H_2O leachates									
SLT proc. R	3590	615	123	73	1.4	543	112	0	$1.49\ 10^5$
IUCS	3211	500	98	67		440	79.2	0	$1.86\ 10^5$
Minn.	2320	44	72	56		440	60	8.4	

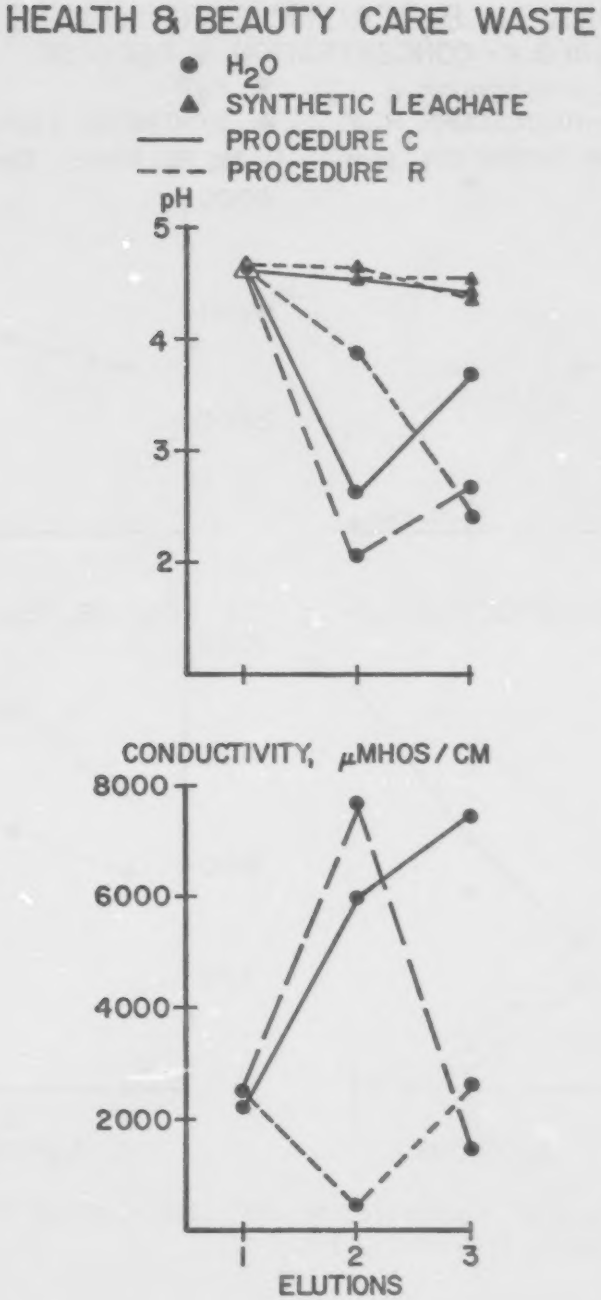


Figure 34. pH and specific conductance curves for Health and Beauty Care Waste, SLT.

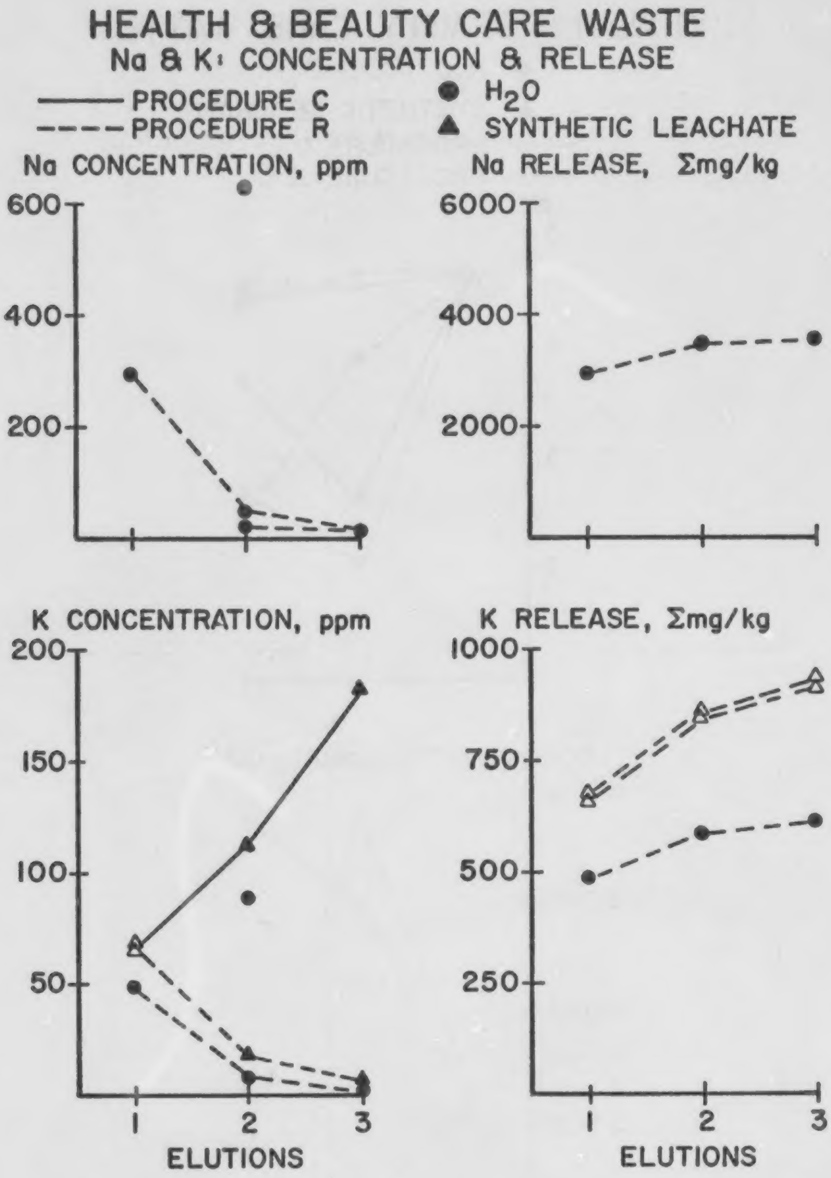


Figure 35. Na and K concentration and release curves for Health and Beauty Care Waste, SLT.

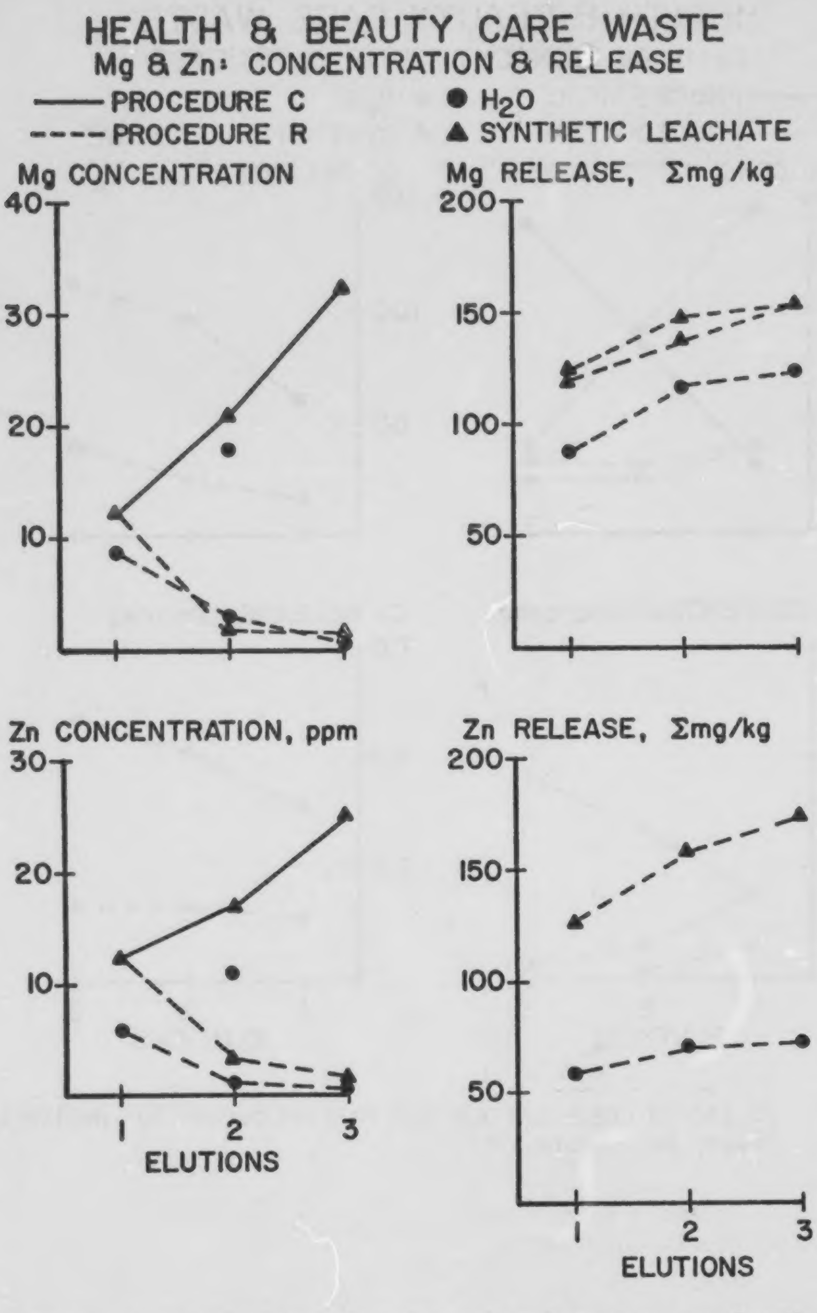


Figure 36. Mg and Zn concentration and release curves for Health and Beauty Care Waste, SLT.

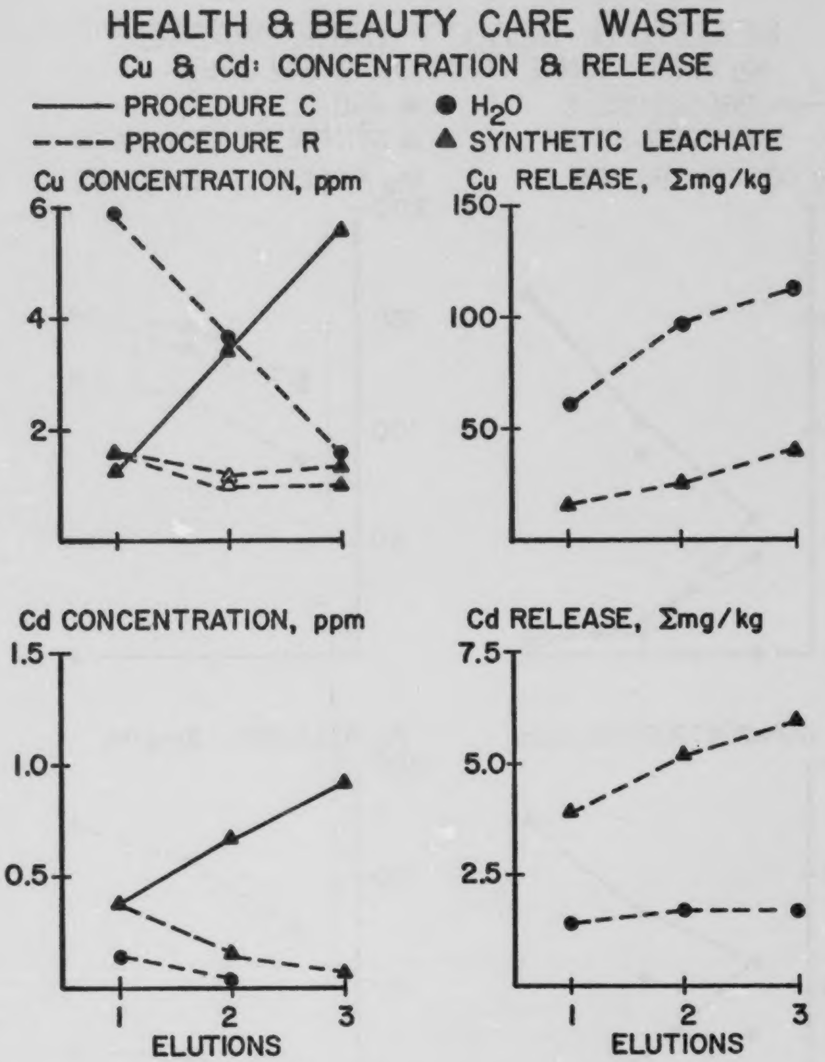


Figure 37. Cu and Cd concentration and release curves for Health and Beauty Care Waste, SLT.

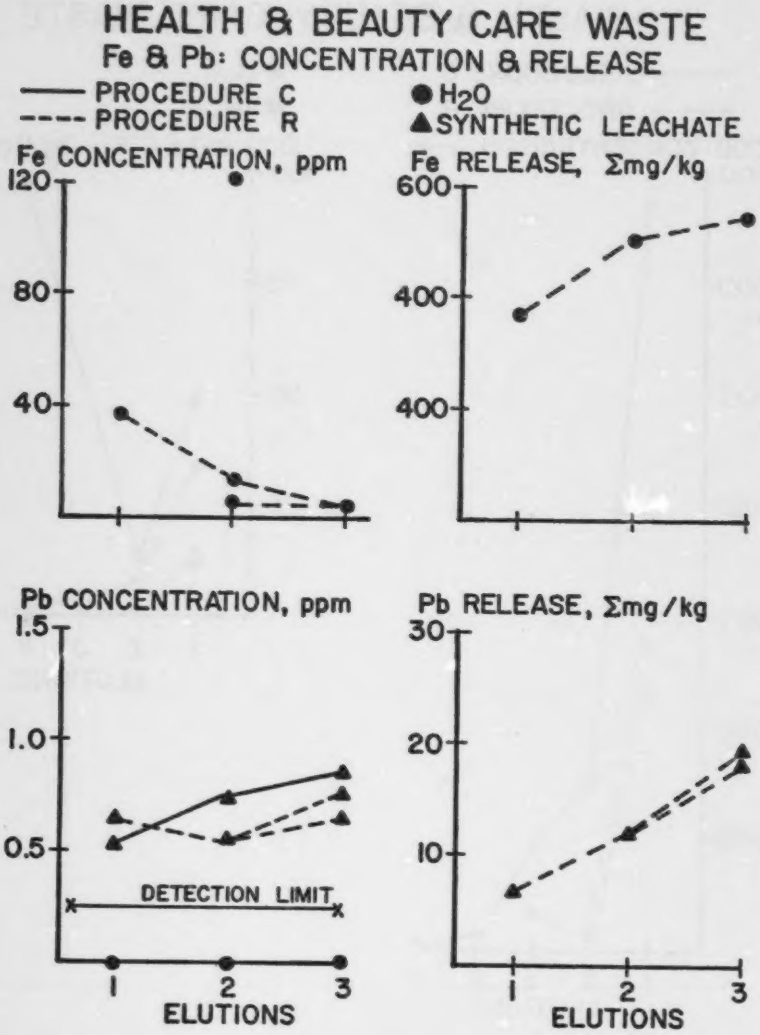


Figure 38. Fe and Pb concentration and release curves for Health and Beauty Care Waste, SLT.

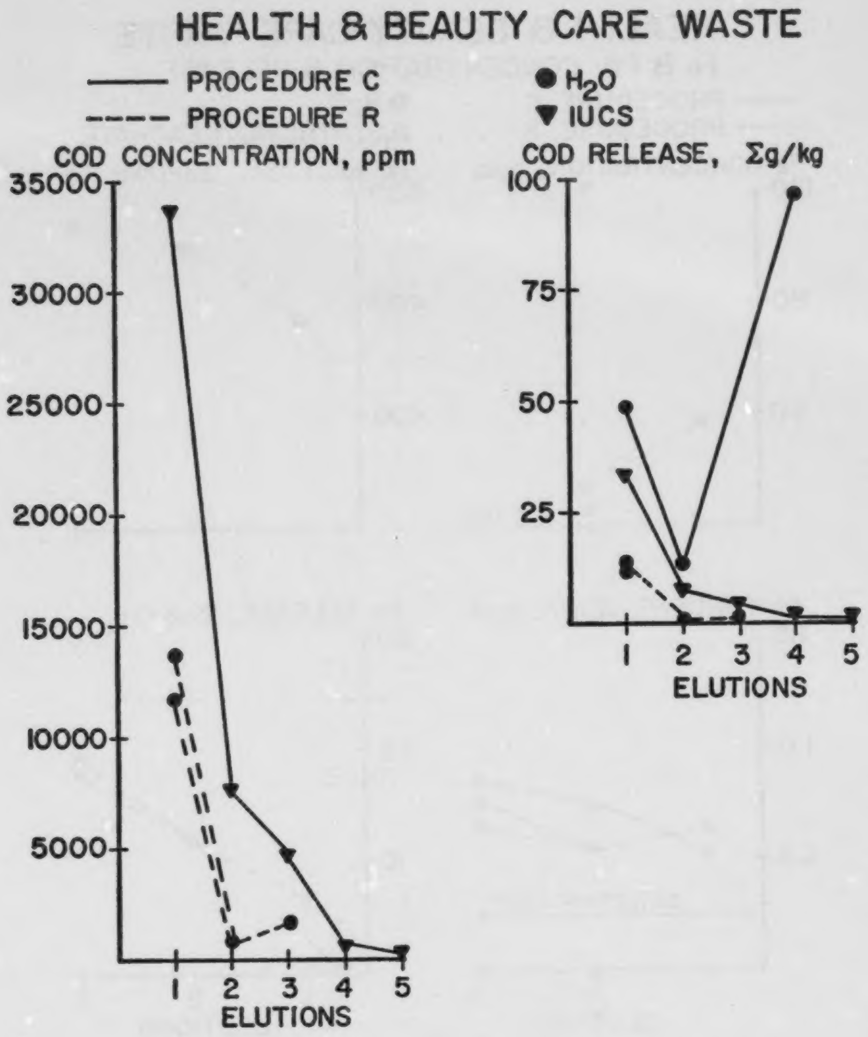


Figure 39. COD concentration and release curves for Health and Beauty Care Waste, SLT.

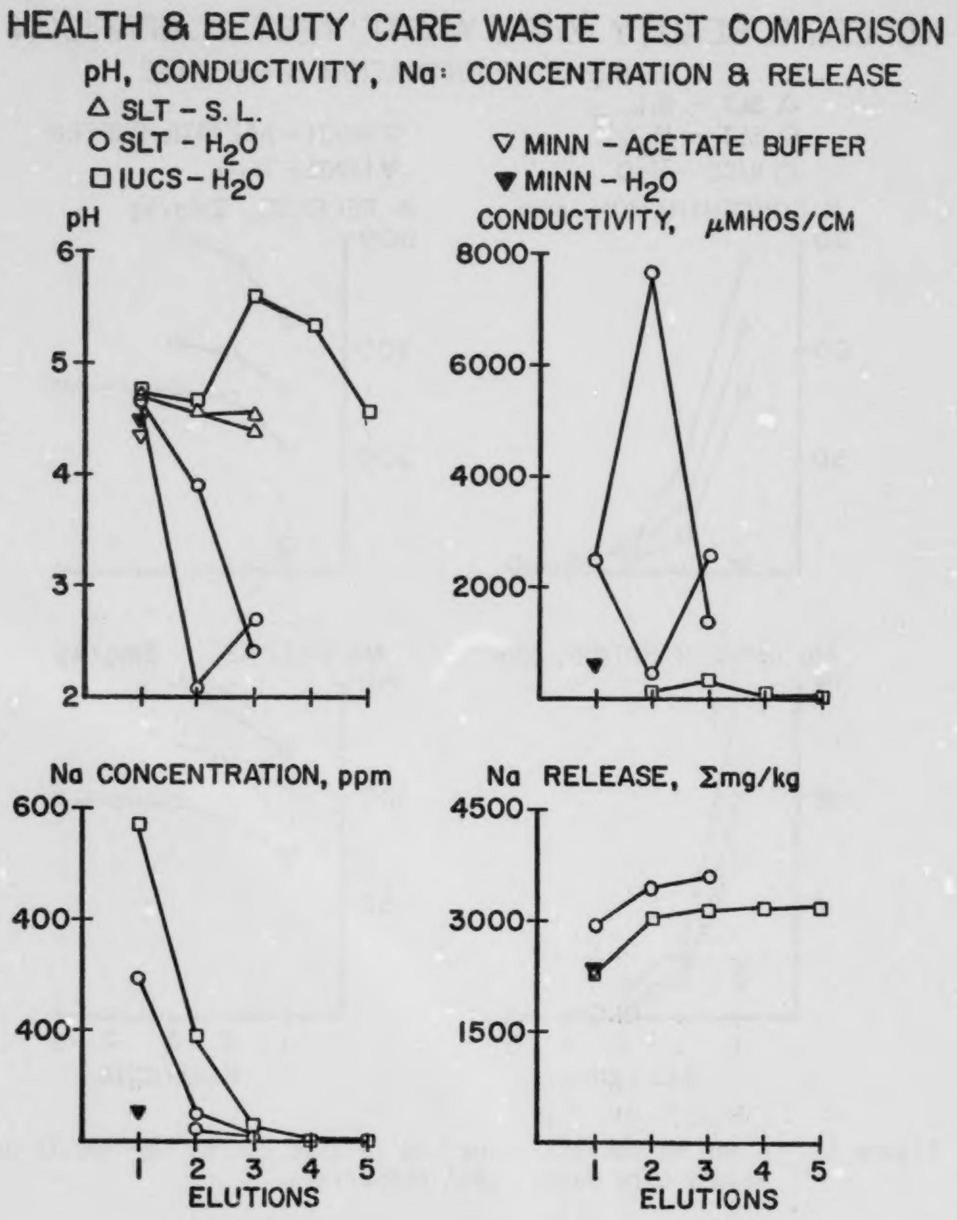


Figure 40. pH, specific conductance, and Na concentration and release curves for Health and Beauty Care Waste, test comparison.

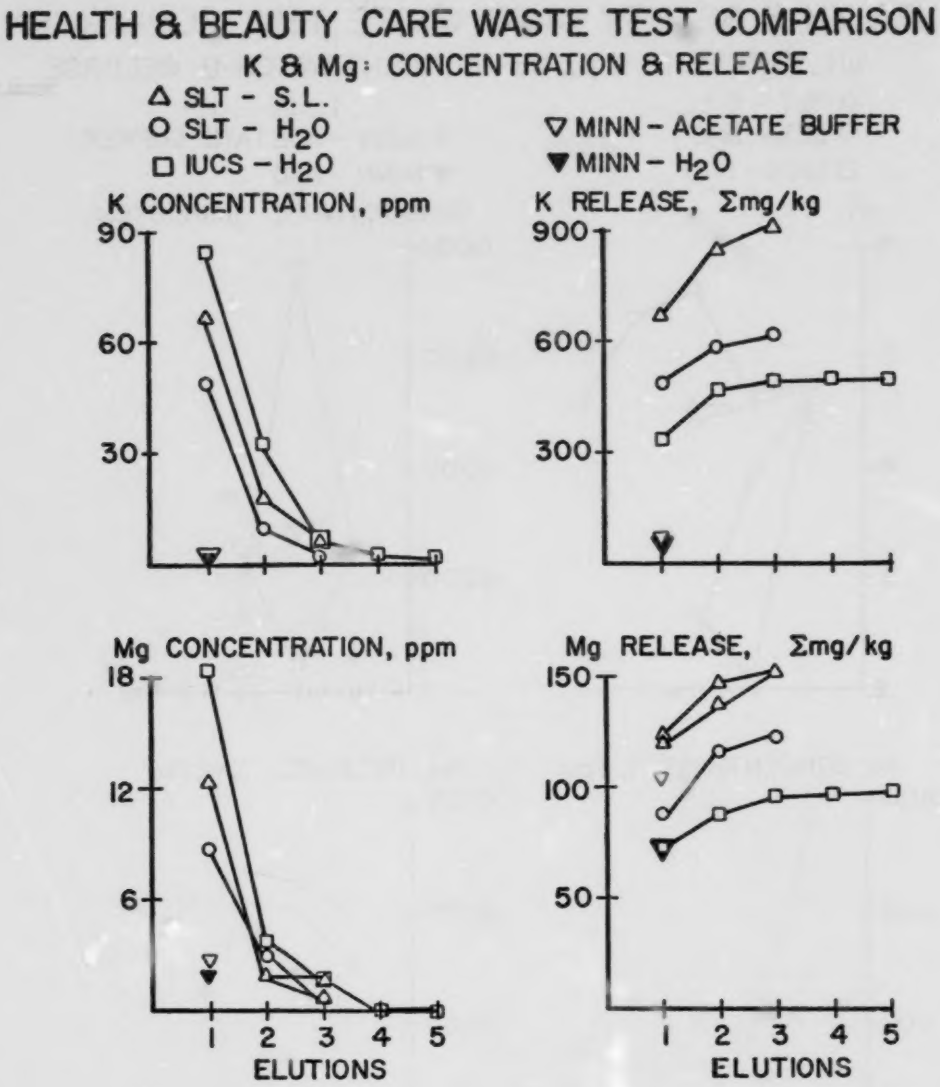


Figure 41. K and Mg concentration and release curves for Health and Beauty Care Waste, test comparison.

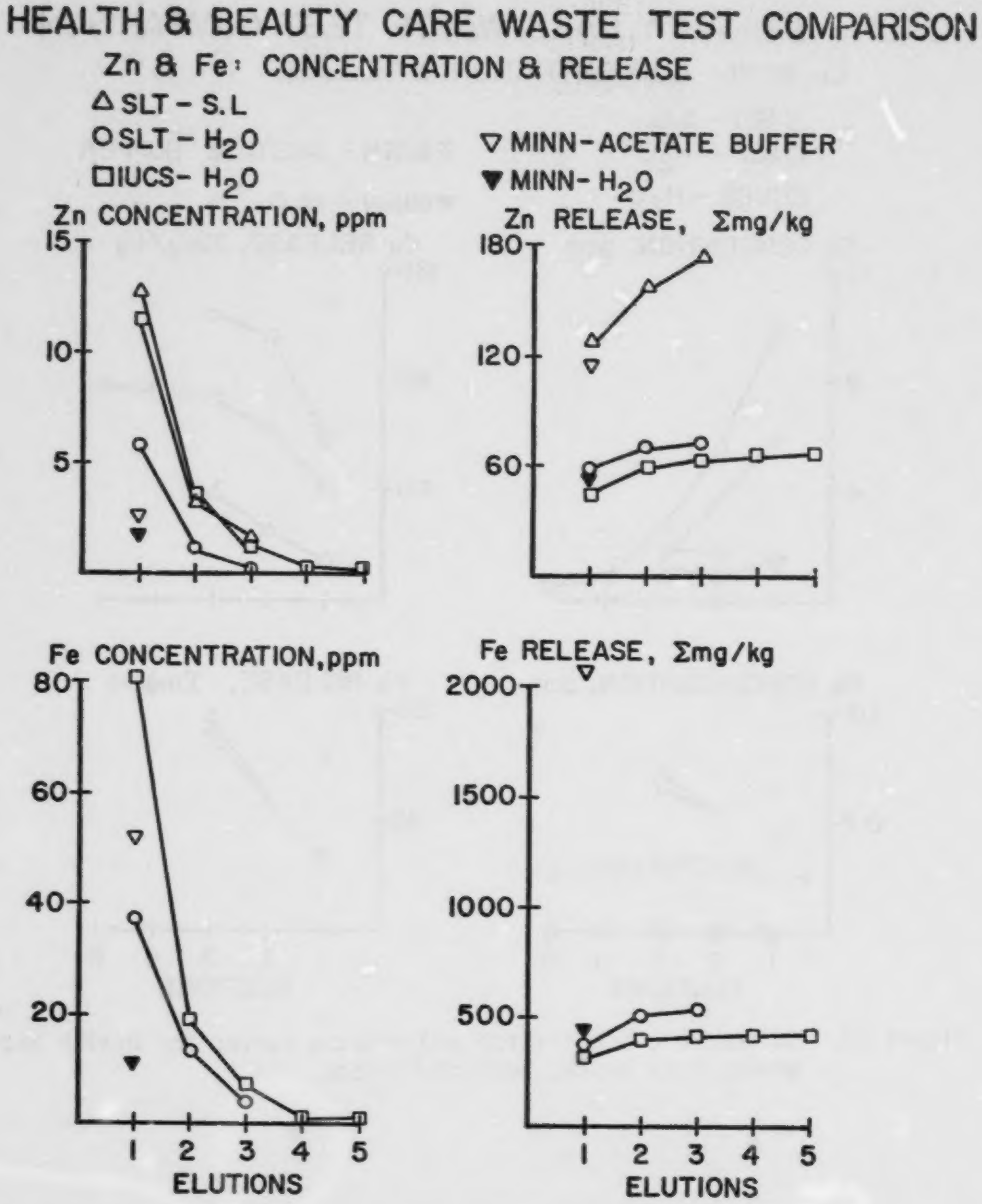


Figure 42. Zn and Fe concentration and release curves for Health and Beauty Care Waste, test comparison.

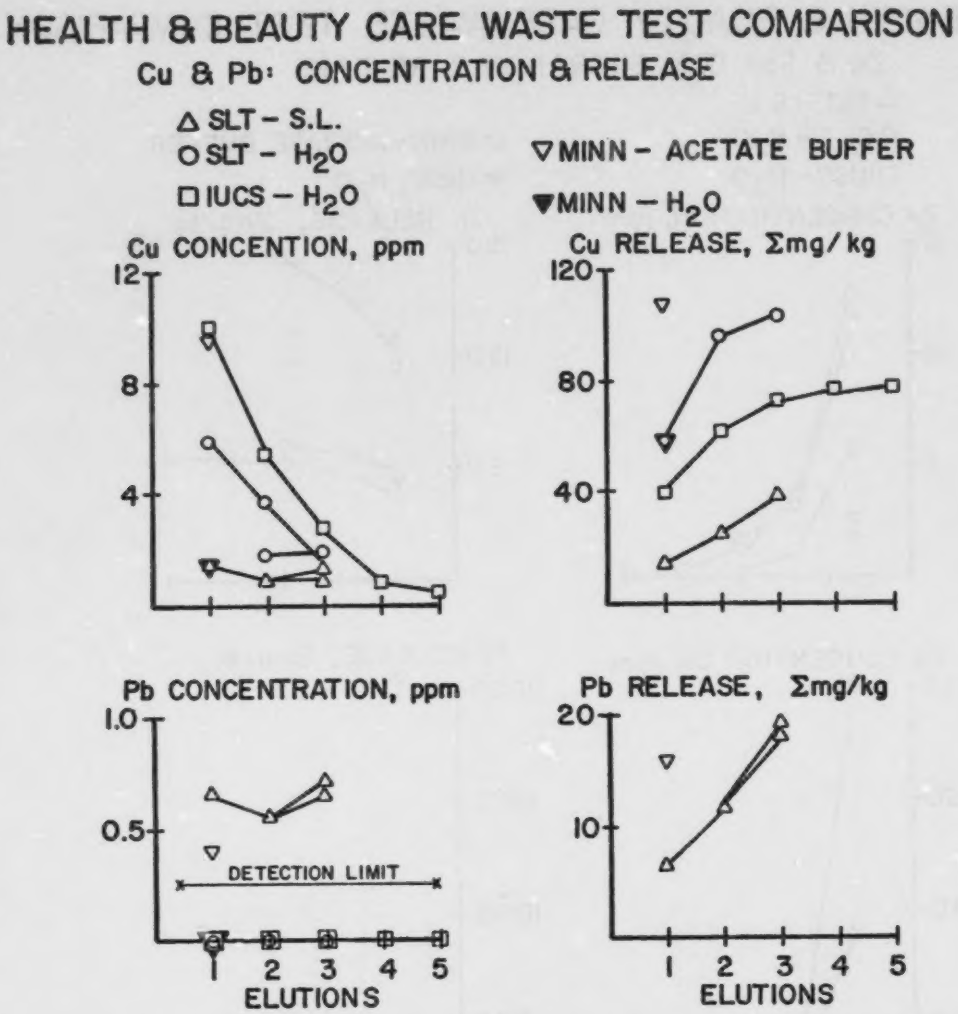


Figure 43. Cu and Pb concentration and release curves for Health and Beauty Care Waste, test comparison.

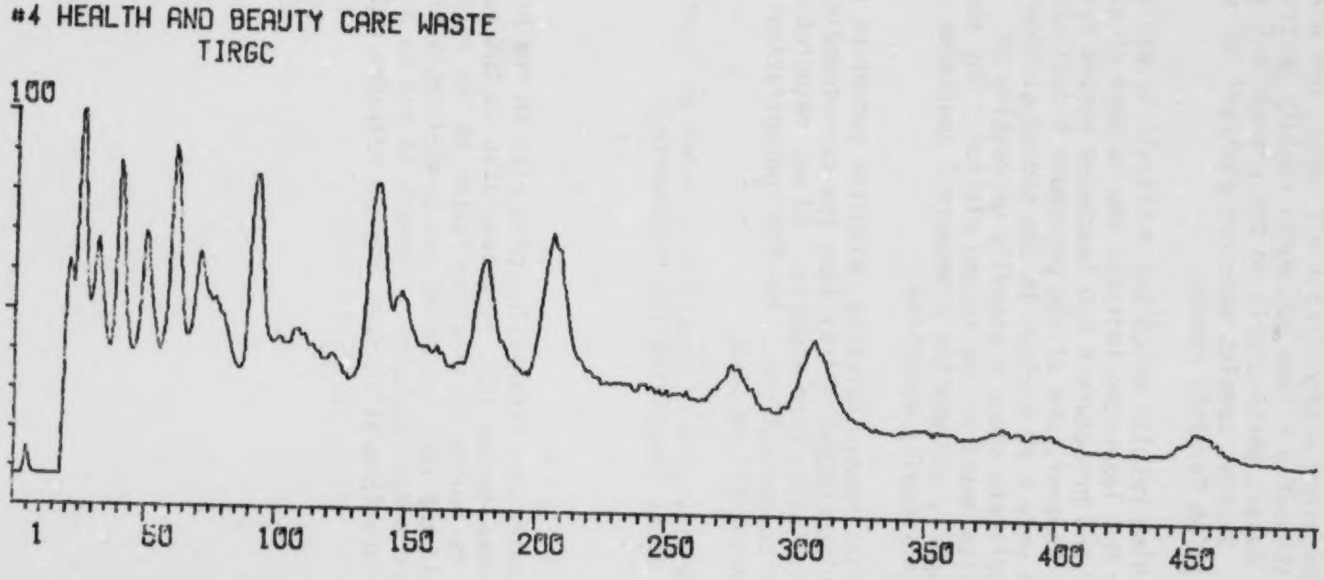


Figure 44. Total ion reconstructed gas chromatogram of Health and Beauty Care Waste, hexane extract.

Discussion

SLT--

The H_2O leachates contained a significant oil layer, one which was emulsified when passing through a filter but which rapidly separated on standing. The heavy oil layer, particularly in the procedure C leachates made analysis difficult. Several samples were not analyzed for parameters measured by atomic absorption for this reason.

The waste gave leaching results which are difficult to explain. For example, the pH data for H_2O leachates indicate the release of acidic materials. Both procedure C and procedure R H_2O leachates become more acidic in successive elutions. However, one of the procedure R duplicates and the procedure C leachate show a pH minimum in the second elution, while the other procedure R duplicate shows a steadily decreasing pH. The duplicates are two pH units apart on the second elution. Why the duplicates should be so far apart, and why the procedure C leachates should show a minimum are not known nor easily explained.

The inorganic elements behave normally, with the exception of Cu. The H_2O leachates had higher Cu concentrations than the corresponding SL leachates. Cu was released in fairly high amounts. Cd was detectable although was not released in high concentrations. The COD concentrations were very high indicating the observed oil release.

The TIRGC from GC-MS analysis of organics is shown as Figure 44. Peaks were not required to be identified for this waste.

Test Comparison--

Test comparison results are interesting primarily in the higher Fe and Cu concentrations, seen in the IUCS leachates than in the acid leachates. pH does not seem to be the controlling factor in the release of these metals. The COD of the IUCS leachates was considerably higher than that of the SLT procedure R H_2O leachates. Perhaps Fe and Cu are complexed with organics or are in organic form and are released with the organic materials.

TABLE 22. FOOD GRADE WASTE: DESCRIPTION AND SUMMARY OF RESULTS

Waste Number 5, ECHO, Inc.	
Physical Description:	Fatty layer floating on water. Fat layer looks like oily brown corn mush.
Chemical Analysis:	
ECHO	pH 8.7, sus. solids 1.3%, Ash 1%, Cd .003 ppm, Hg 0, pB .001 ppm, Cr .40 ppm, Zn .011 ppm, Cu .001
Wisconsin (solid):	20% volatile at 105°C for 24 hours
Organics:	None specified
Trace Metals of Interest	None
Sample Preparation:	Solid layer sampled directly
Comments:	Some leachate absorbed by waste in procedure C samples.

(continued)

TABLE 22 (continued)

Maximum Concentration and Release

Concentration, mg/l

Acid leachates	Na	K	Mg	Zn
SLT procedure C, SL		36.5	19.9	147.
SLT procedure R, SL		11.5	5.45	26.3
Minn.		1.4	.45	1.8
H_2O leachates				
SLT procedure C	106.9	18.0	16.0	4.9
SLT procedure R	24.0	5.1	5.0	3.3
IUCS	45.	8.5	8.	3.9
Minn.	2.4	.39	.37	1.0

Release, mg/kg

Acid leachates	Na	K	Mg	Zn
SLT procedure R, SL		209.	74.6	627.
Minn.		56.	18.	72.
H_2O leachates				
SLT procedure R	319.	64.	56.8	42.
IUCS	234.	44.	41.1	27.8
Minn.	96.	16.	15.6	38.

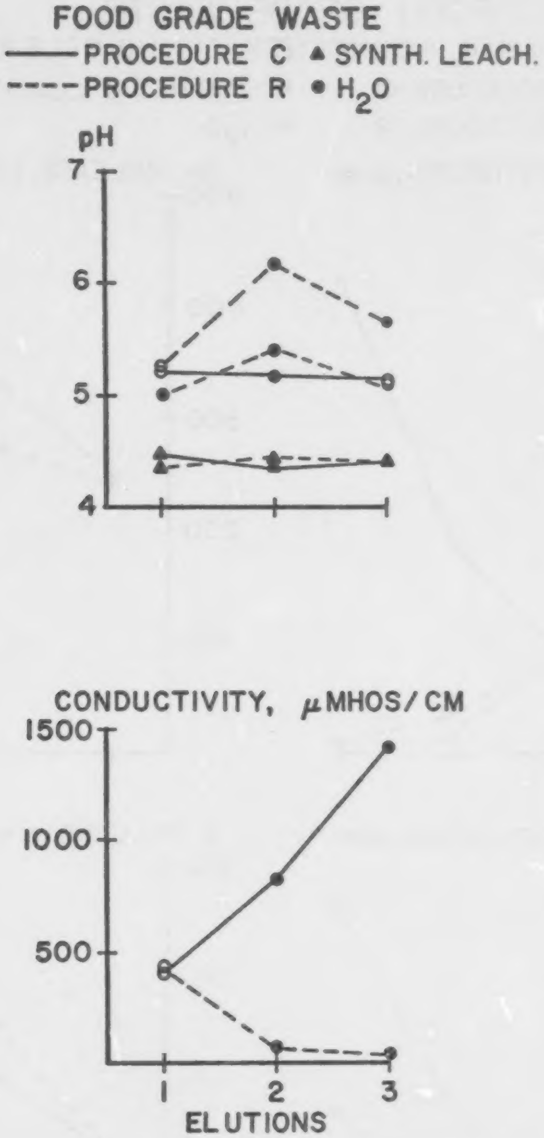


Figure 45. pH and specific conductance curves for Food Grade Waste, SLT.

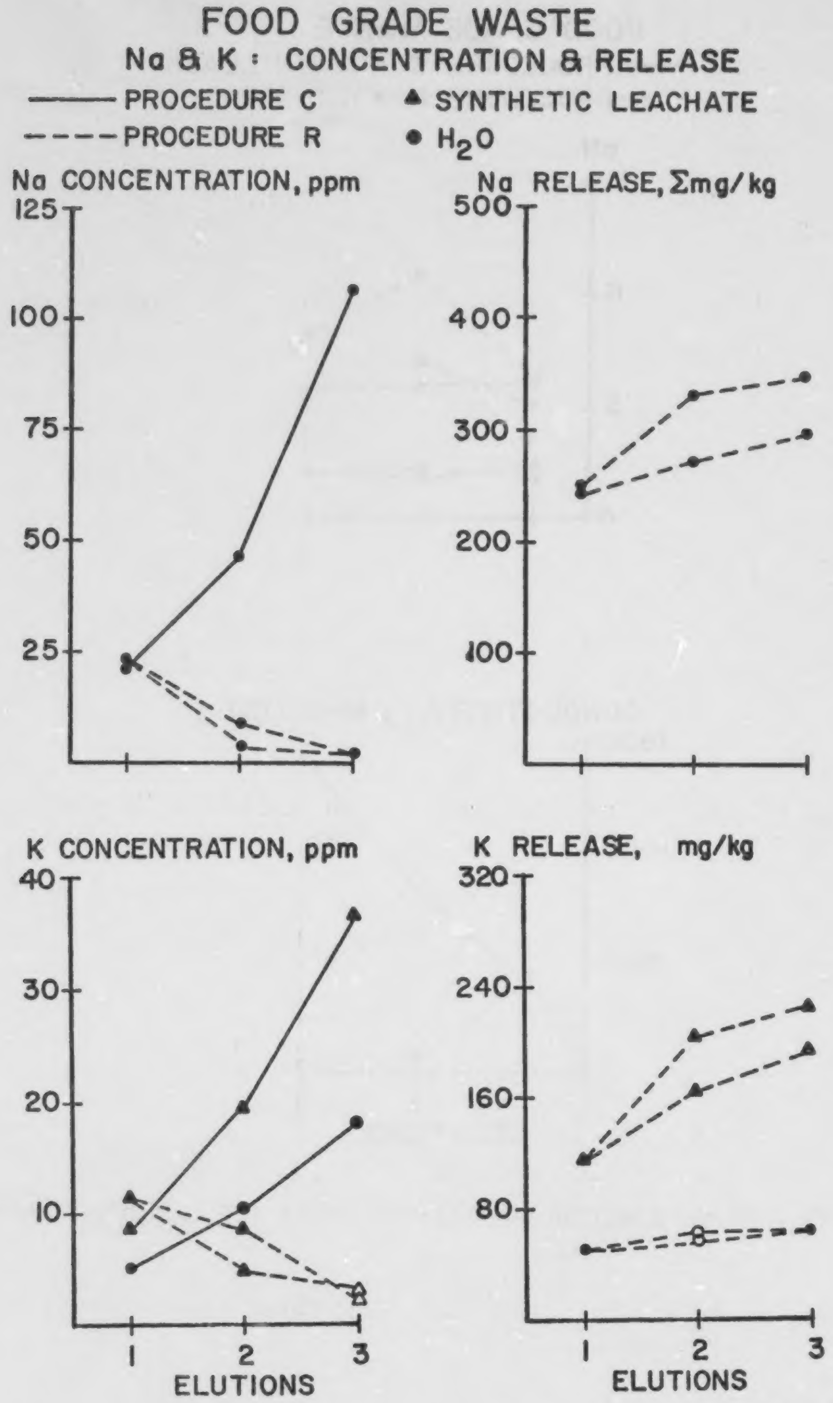


Figure 46. Na and K concentration and release curves for Food Grade Waste, SLT.

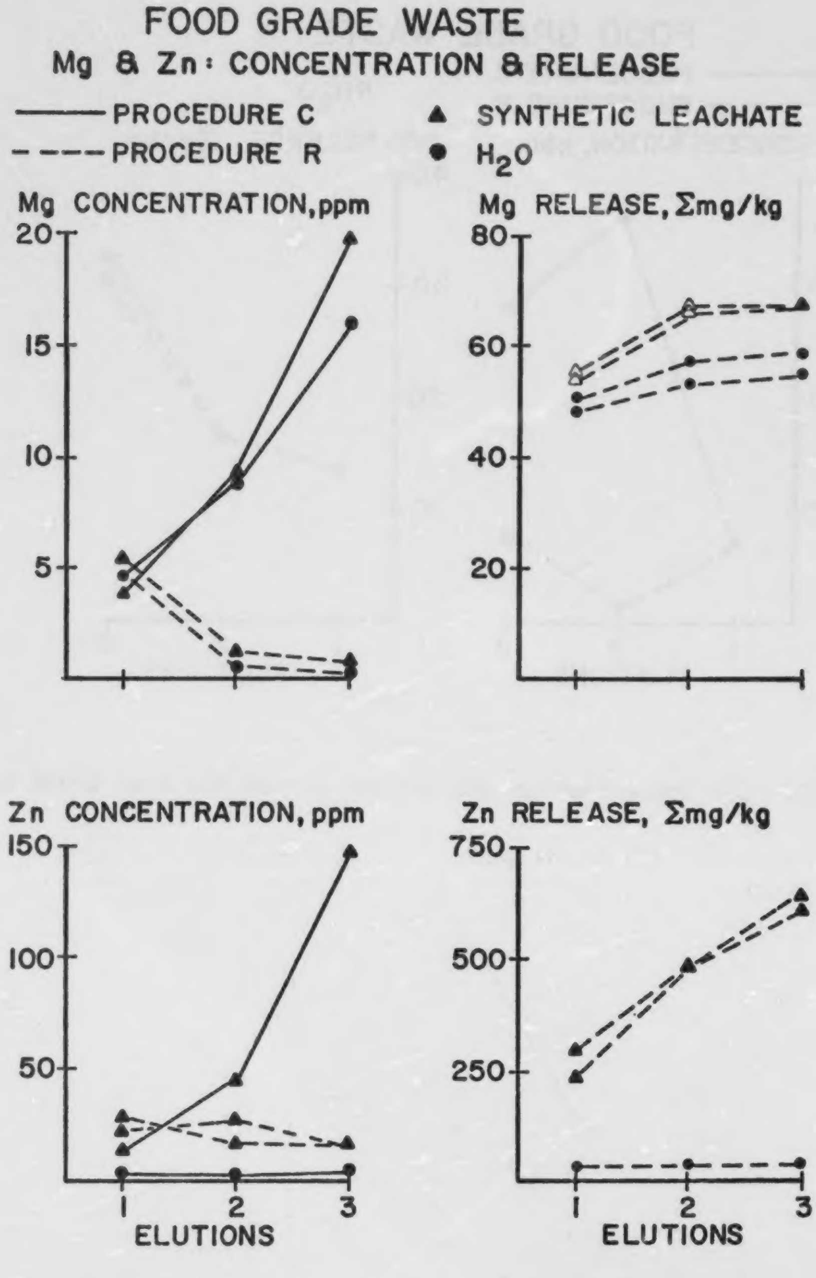


Figure 47. Mg and Zn concentration and release curves for Food Grade Waste, SLT.

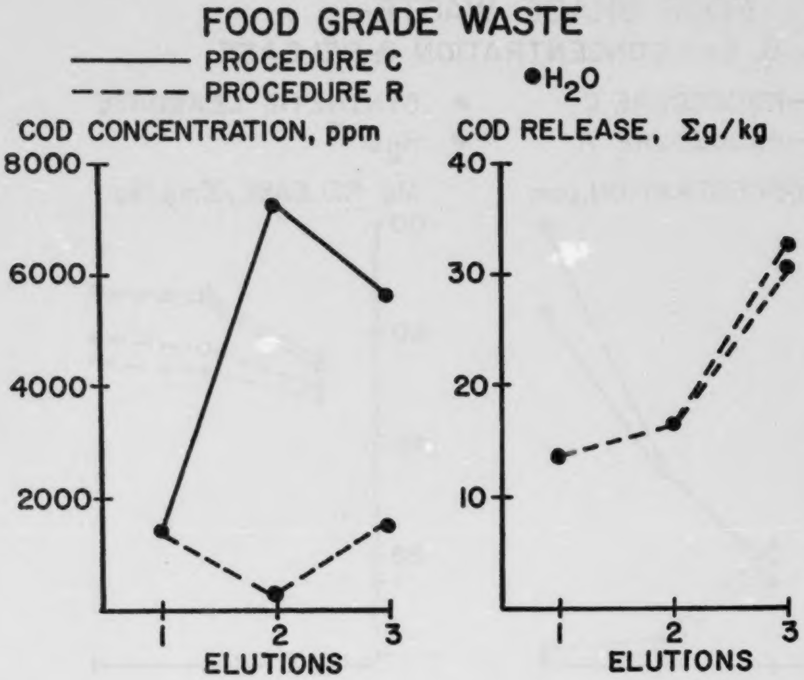


Figure 48. COD concentration and release curves for Food Grade Waste, SLT.

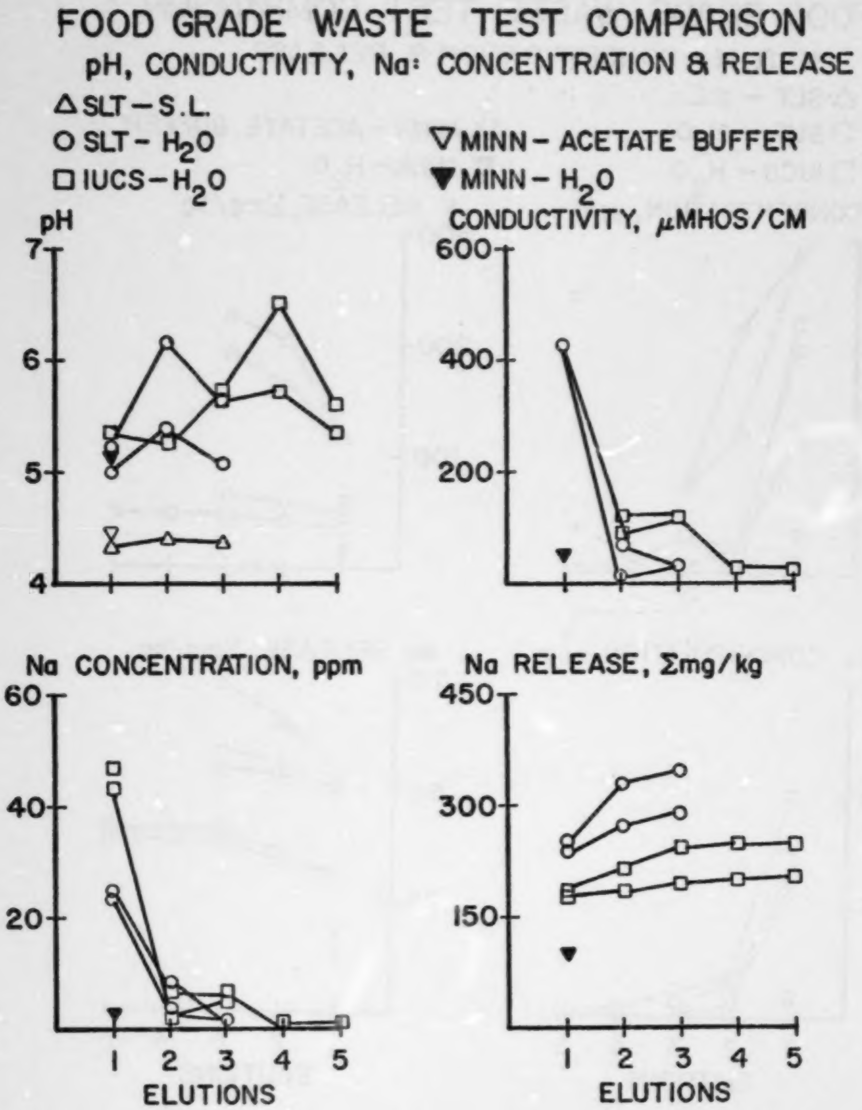


Figure 49. pH, specific conductance, and Na concentration and release curves for Food Grade Waste, test comparison.

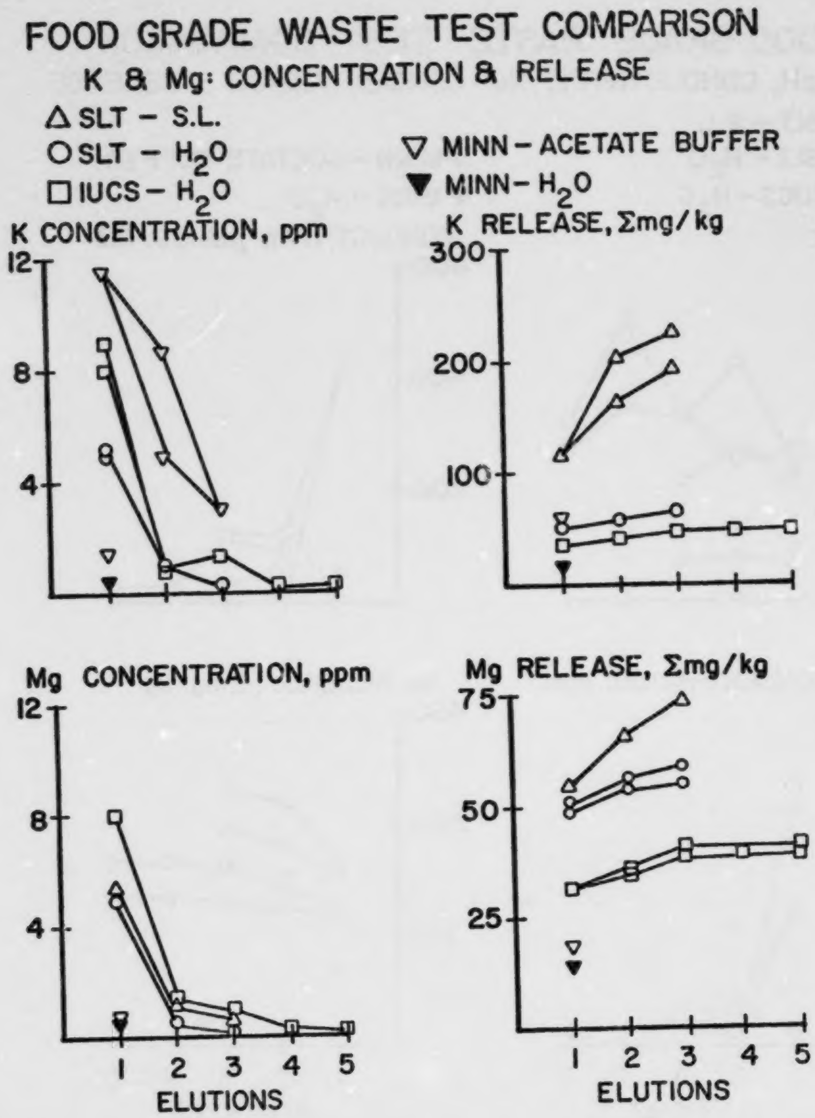


Figure 50. K and Mg concentration and release curves for Food Grade Waste, test comparison.

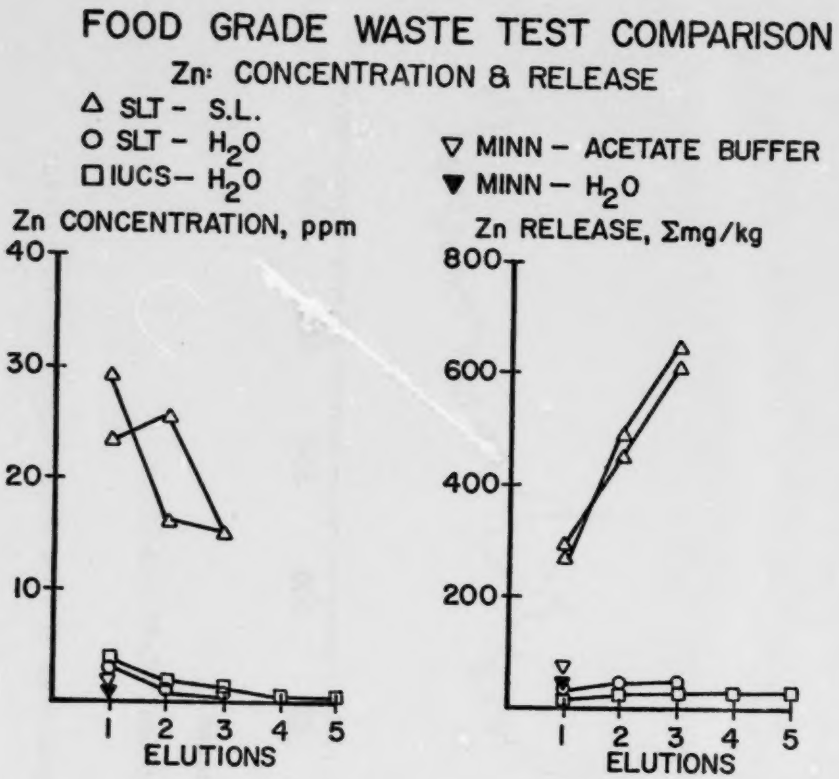
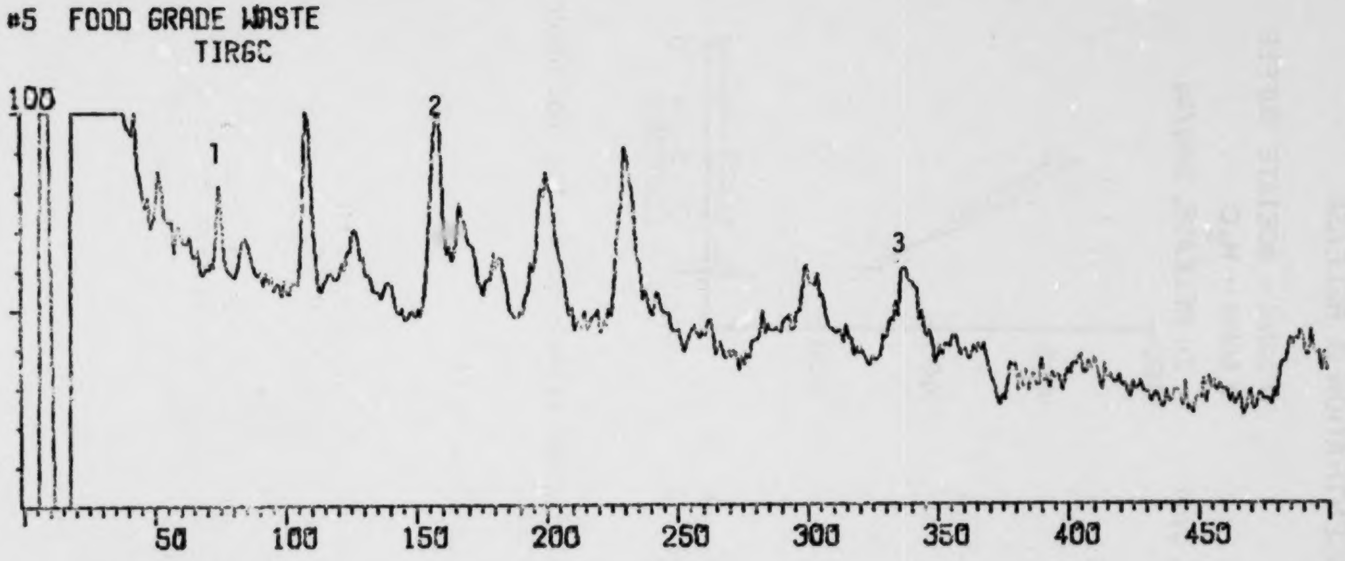


Figure 51. Zn concentration and release curves for Food Grade Waste, test comparison.



1. Tetradecane; 2. hexadecane; 3. octadecane.

(See Figures A-10, A-11, and A-12 for additional GC-MS results.)

Figure 52. Total ion reconstructed gas chromatogram of Food Grade Waste, hexane extract.

TABLE 23. ADHESIVE WASTE #6: DESCRIPTION AND SUMMARY OF RESULTS

Waste Number 6, ECHO, Inc.

Description:

Pressure sensitive adhesives, will contain tackifiers, NBR, and SBR cuts in hexane, and some filler, predominately carbonates and metal oxides. Very sticky, viscous liquid. Difficult to work with or to clean from glassware or hands.

Chemical Analysis:

ECHO: pH 7.2, suspended solids 0.17%, Cd 0.06 ppm, Pb 0.54 ppm, Cr 0.13 ppm, Zn 1.21 ppm, Cu 0.08 ppm

Wisconsin: 99.7% volatile at 600°C, 34% volatile at 105°C for 24 hours

Organics: Not analyzed. Sample solidified and clogged soxhlet extractor.

Trace Metals of Interest: Zn, Pb, Cr

Sample Preparation:

Would not filter, sampled directly.

Comments:

Difficult waste to work with. Glues caps onto bottles, filters onto filter frits. Glassware was cleaned by burning the waste off glassware at 600°C, then washing.

In procedure C, SLT, some leachate was absorbed by the solid. It was very difficult to remove all the solids from the test vessel in this procedure, so old waste was not completely removed before fresh waste was added.

TABLE 23 (continued)

Maximum Concentration and Release

Concentration, mg/l

Acid leachates	Na	K	Zn	Pb	Cr
SLT proc. C, SL		2.7	2.20	b.d.	b.d.
SLT proc. R, SL		2.5	.94	b.d.	b.d.
Minn.		.99	.16		

H_2O leachates	Na	K	Zn
SLT proc. C	31.1	1.0	2.85
SLT proc. R	2.5	.35	.51
IUCS	2.9	.16	.82
Minn.	.6	.05	.05

Release, mg/kg

Acid leachates	Na	K	Zn
SLT proc. R, SL		53.6	18.4
Minn.		39.6	6.4

H_2O leachates	Na	K	Zn
SLT proc. R	46.8	5.7	5.1
IUCS	18.4	6.5	3.3
Minn.	25.6	2.	2.

Pb and Cr below detection.

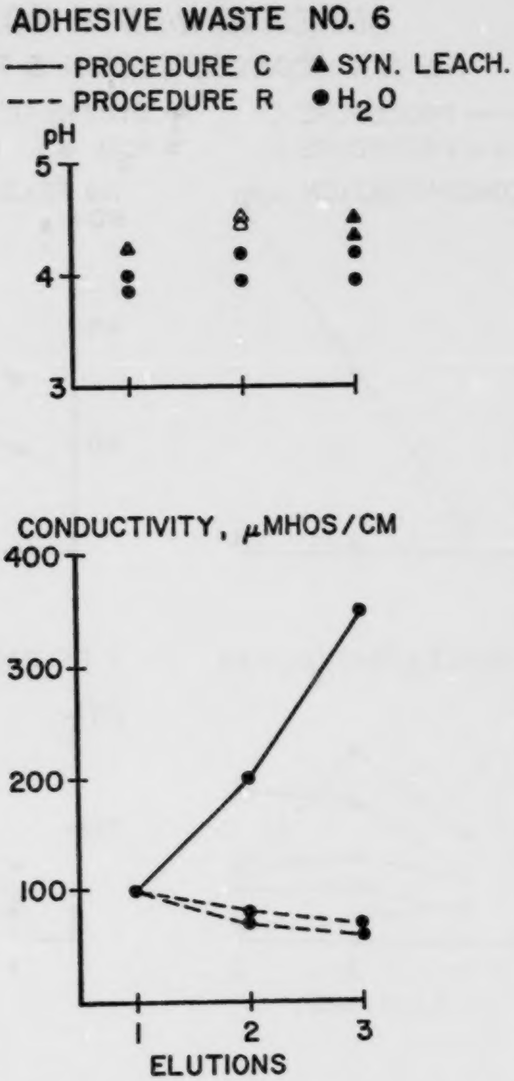


Figure 53. pH and specific conductance curves for Adhesive Waste #6, SLT.

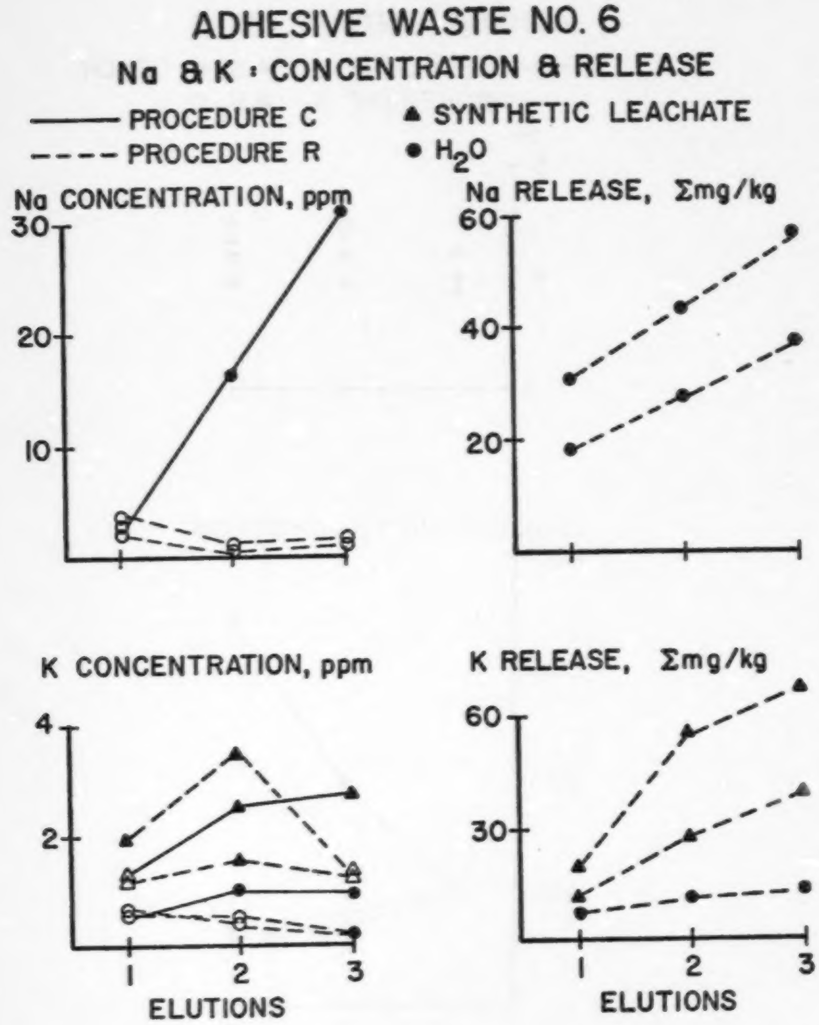


Figure 54. Na and K concentration and release curves for Adhesive Waste #6, SLT.

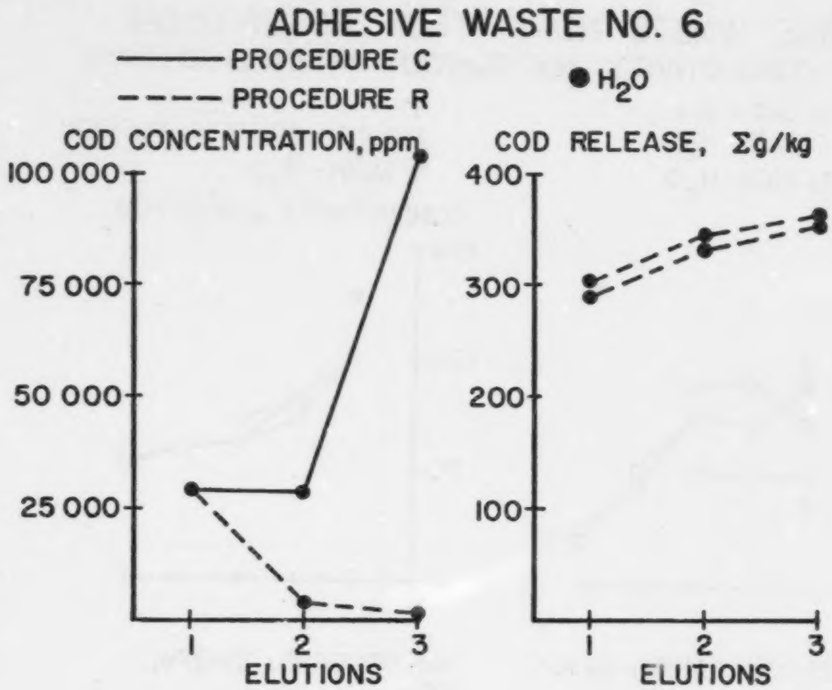


Figure 55. COD concentration and release curves for Adhesive Waste #6, SLT.

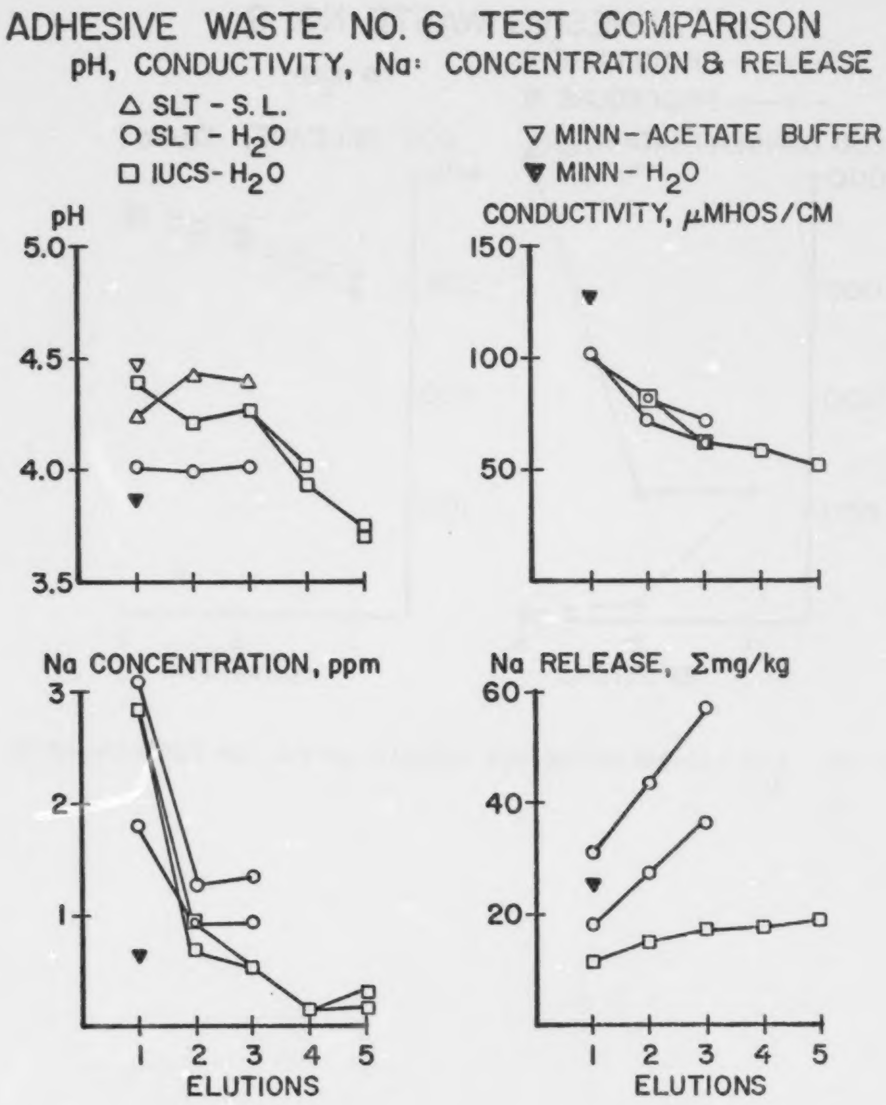


Figure 56. pH, specific conductance, and Na concentration and release curves for Adhesive Waste #6, test comparison.

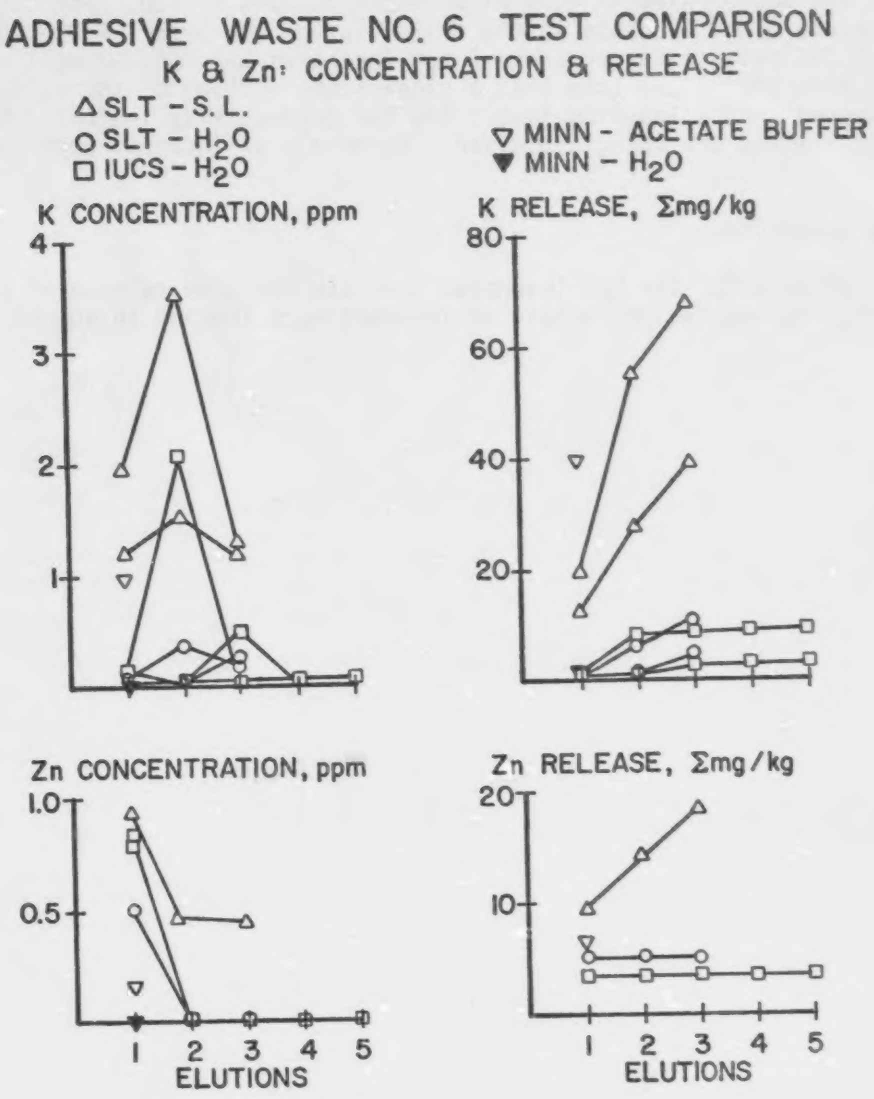


Figure 57. K and Zn concentration and release curves for Adhesive Waste #6, test comparison.

Discussion

SLT--

The waste released very high concentrations of COD. The COD in the procedure C H_2O leachate in the third elution was over 100,000 mg/l. The total COD release in procedure R H_2O leachates was 360,000 mg/l. These very high COD values show that a significant portion of the waste is dissolved in the leaching test. The low conductivity indicates that non-ionic species are being dissolved. No metals of interest were leached.

Test Comparison--

pH data for the H_2O leachates indicate the slow release of slightly acidic components. No metals of interest were leached in any of the tests.

TABLE 24. PETROCHEMICAL INDUSTRY WATER-OIL SLUDGE: DESCRIPTION AND SUMMARY OF RESULTS

(Petrochemical Sludge)

Waste Number 7, ECHO, Inc.

Description:

A black, goopey sludge.

Analysis:

ECHO, Inc.	flash point > 150°F, Ash 0.20%, B.T.U.-19,350 BTU/lb, Zn - 187 mg/l, Cu - 39.0 mg/l Pb - 23.2 mg/l, Cr - 2.38 mg/l, Cd - 0.60 mg/l
Wisconsin:	Waste contains 3 fractions: an oil layer, a water layer and solids. Dry solids are 11% by weight. Liquid, 42% H_2O by volume; 58% oil by volume. Solids are 51.3% volatile.
Organics:	Hexadecane ($C_{16}H_{34}$), napthalene ($C_{10}H_8$)
Trace metals of interest:	Cu, Pb, Zn

Sample Preparation:

Sludge stirred vigorously prior to sampling. Centrifuged to separate solids. Liquid layers after centrifuge were filtered separately but contained no solids.

(continued)

TABLE 24 (continued)

Maximum Concentration and Release

			Concentration mg/l			
Acid Leachates	Na	K	Mg	Zn	Pb	Cu*
SLT Proc C, SL		10	360	5.0	.73	b.d.
SLT Proc R, SL		3.5	128	7.0	.98	b.d.
Minn		2.9	22	1.5	.80	b.d.
H_2O Leachates						
SLT Proc C	62	4.9	53	.15	.25	b.d.
SLT Proc R	20.5	.4	17.2	0	.19	b.d.
IUCS	144	2.3	26	0	0	b.d.
Minn	4.2	.2	4.7	0	.30	b.d.
			Release mg/kg			
Acid Leachates						
SLT Proc. R, SL		75	1770	173	24.3	b.d.
Minn		88	880	60	32	b.d.
H_2O Leachates						
SLT Proc R	327	6.2	279	0	1.9	b.d.
IUCS	780	14.4	238	0	0	b.d.
Minn	168	6	188	0	12	b.d.

*Below detection limits.

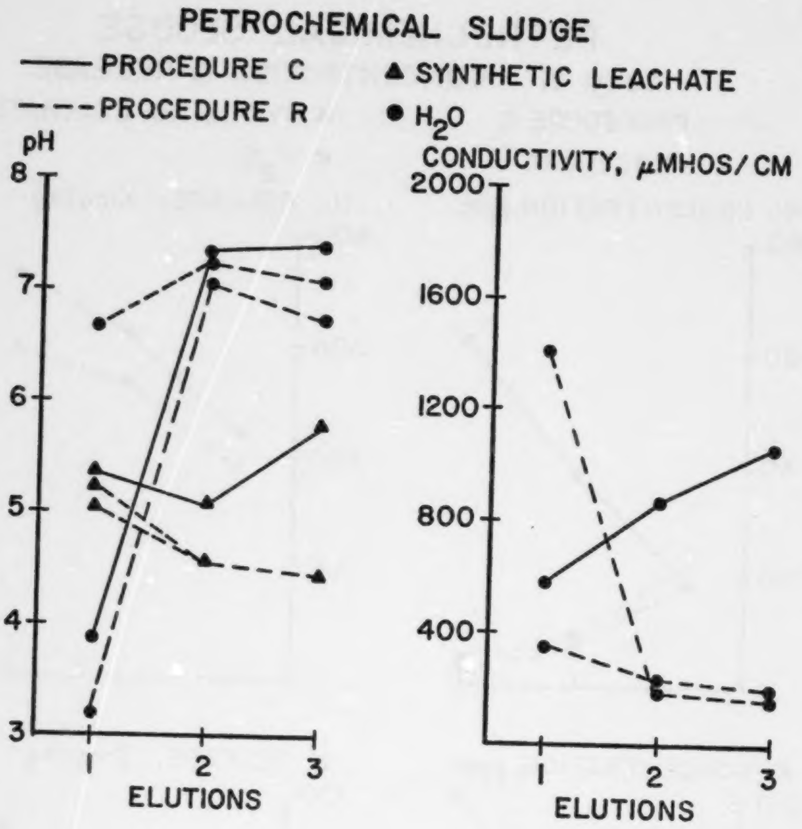


Figure 58. pH and specific conductance curves for Petrochemical Sludge, SLT.

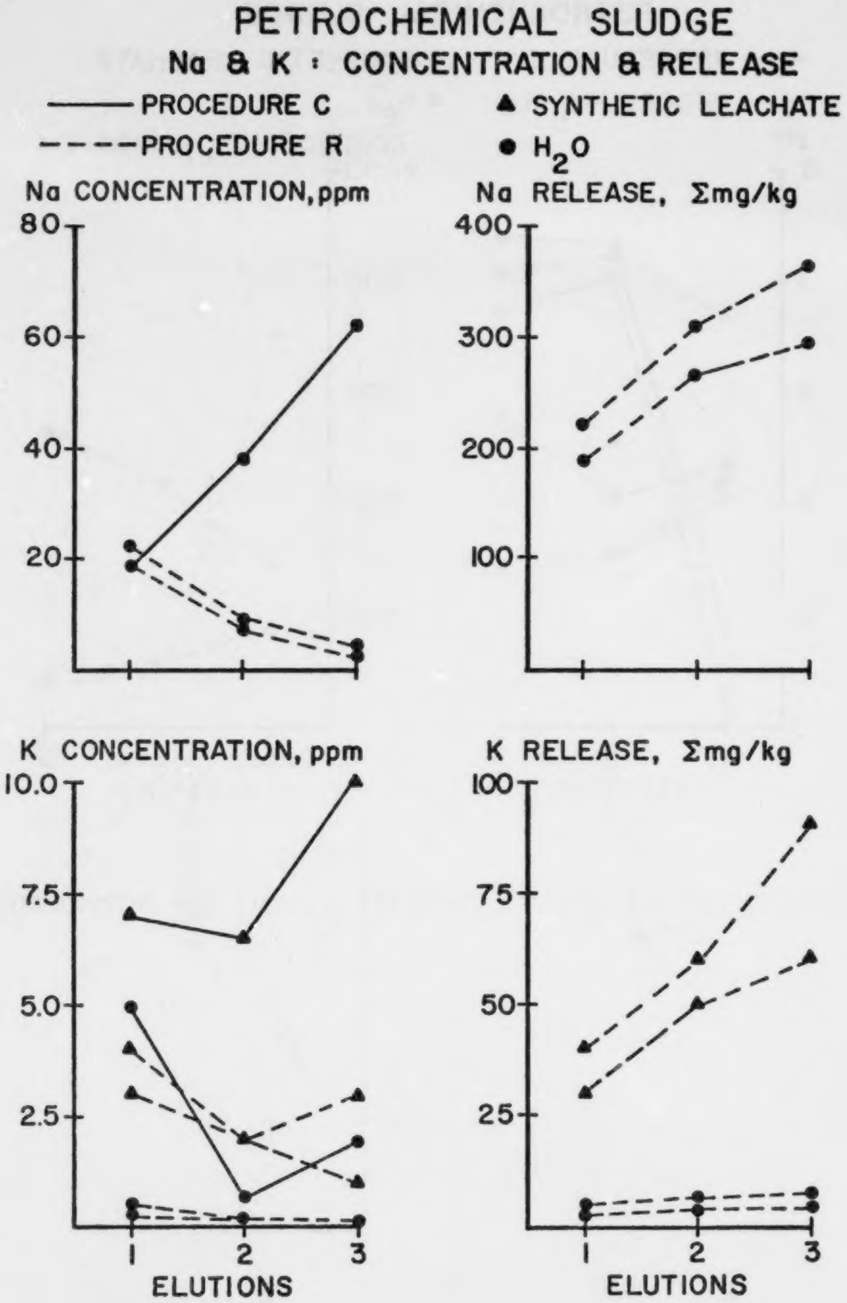


Figure 59. Na and K concentration and release curves for Petrochemical Sludge, SLT.

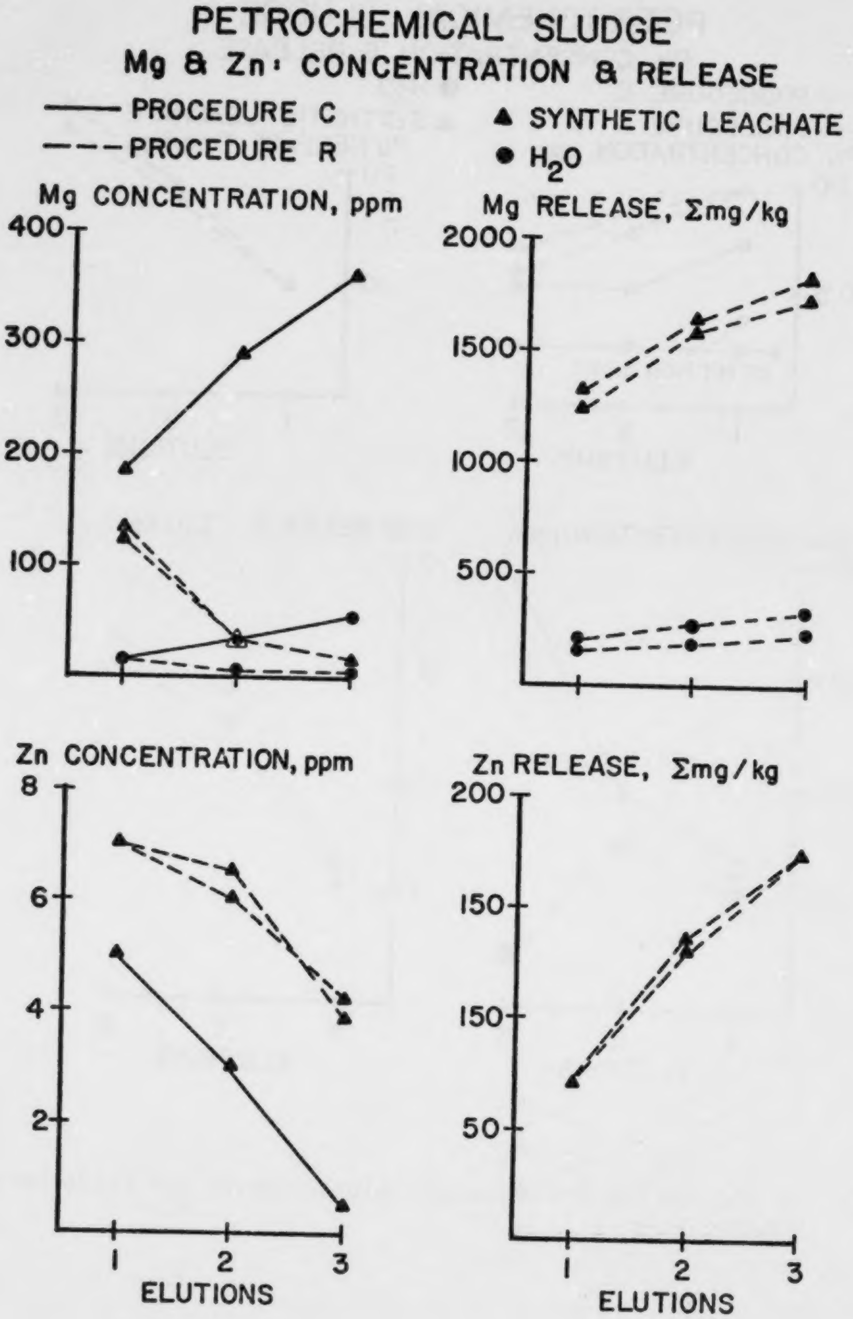


Figure 60. Mg and Zn concentration and release curves for Petrochemical Sludge, SLT.

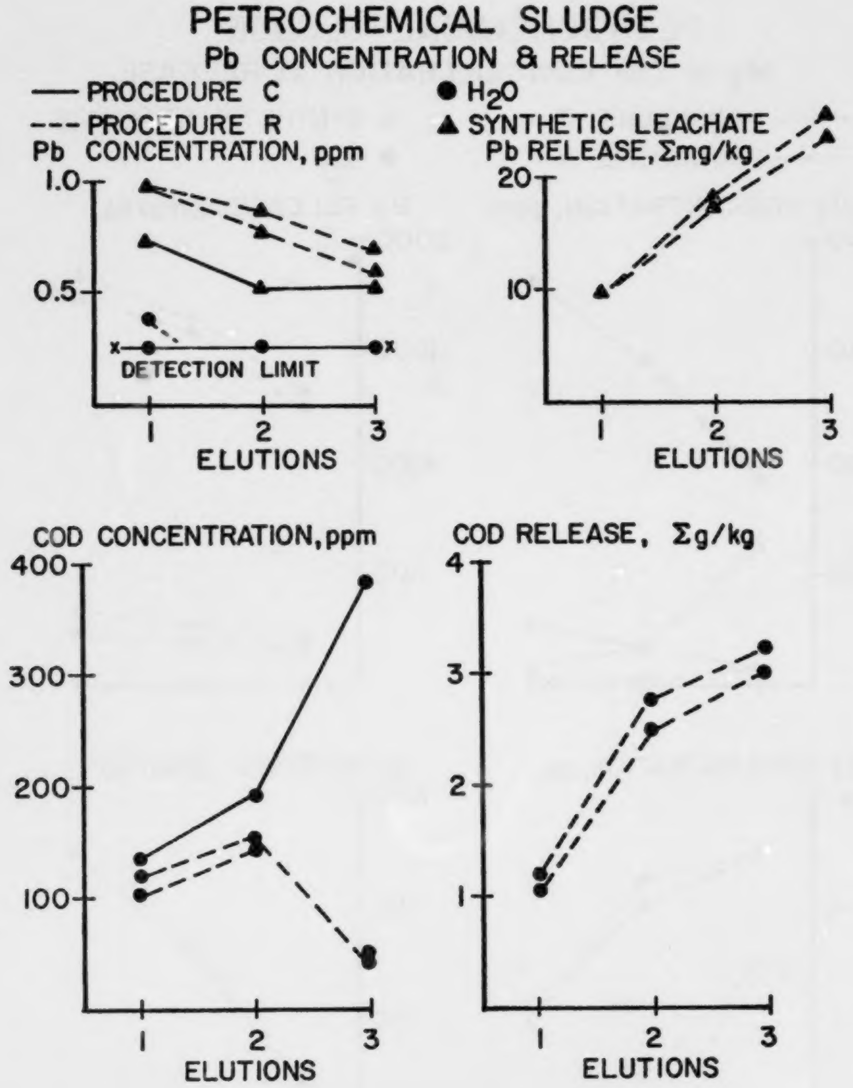


Figure 61. Pb and COD concentration and release curves for Petrochemical Sludge, SLT.

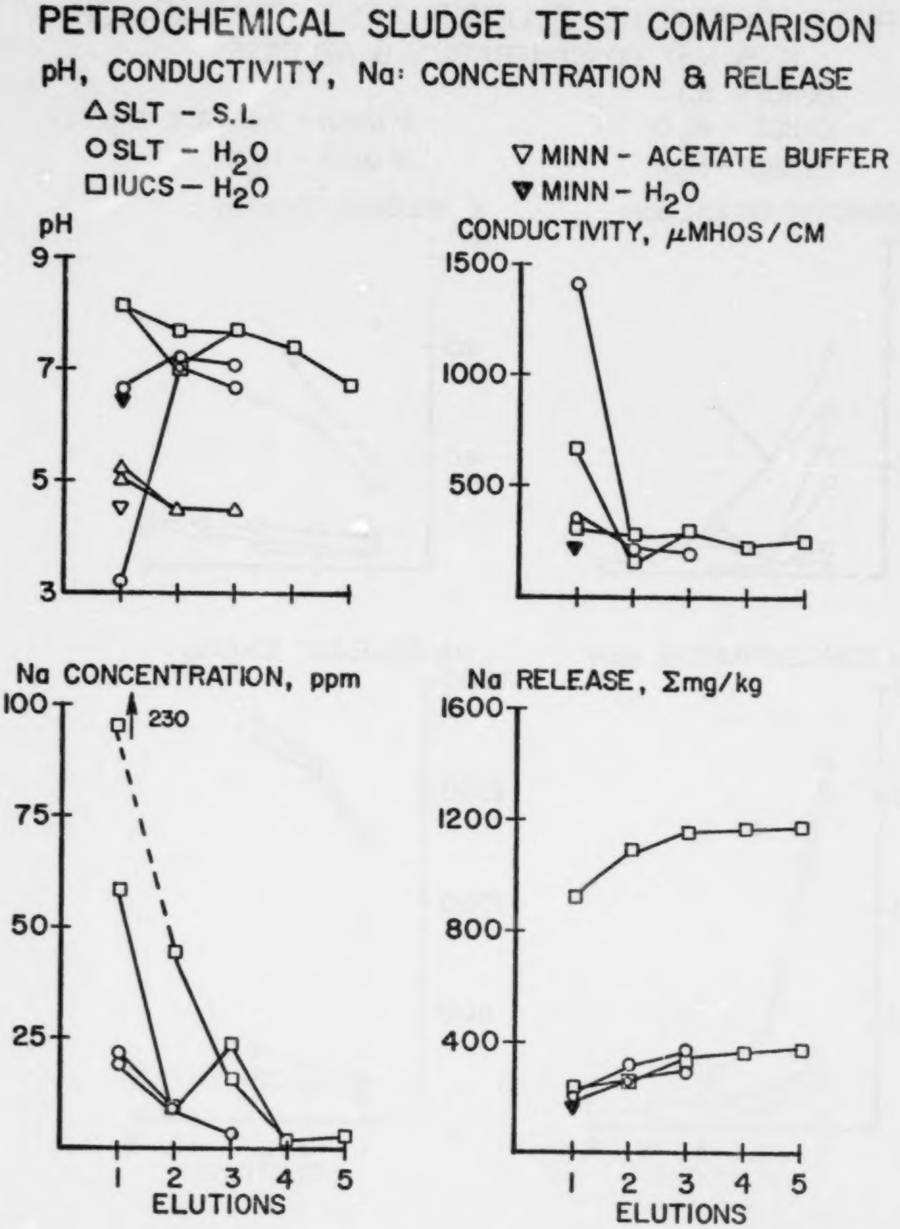


Figure 62. pH, specific conductance, and Na concentration and release curves for Petrochemical Sludge, test comparison.

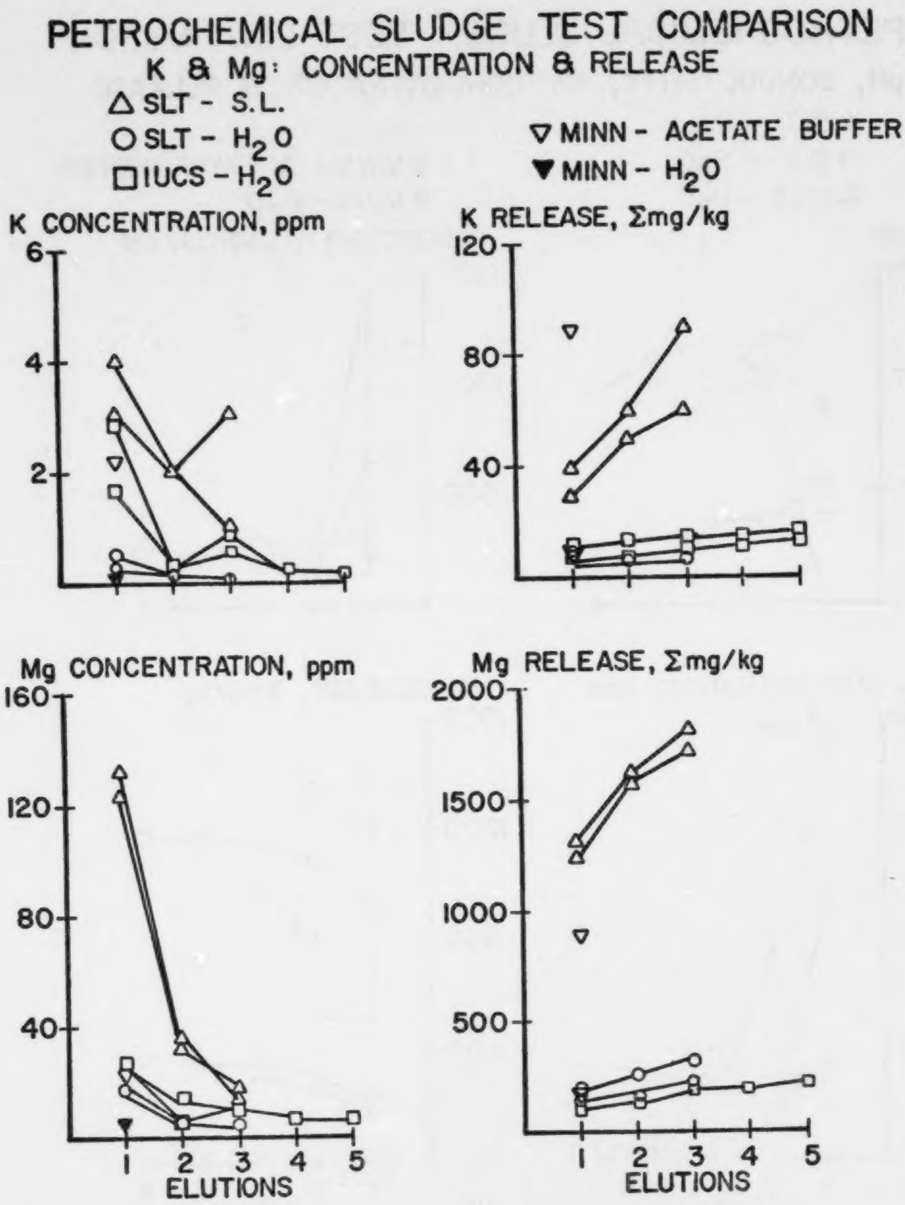


Figure 63. K and Mg concentration and release curves for Petrochemical Sludge, test comparison.

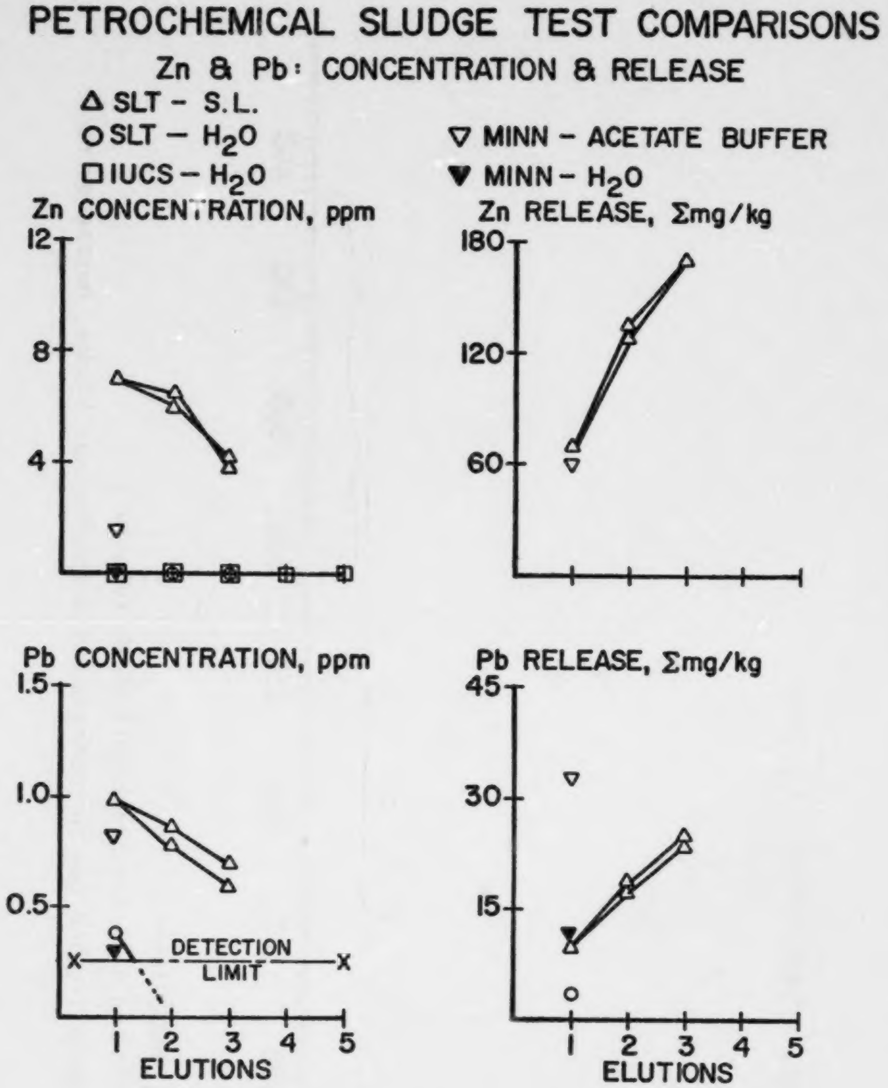
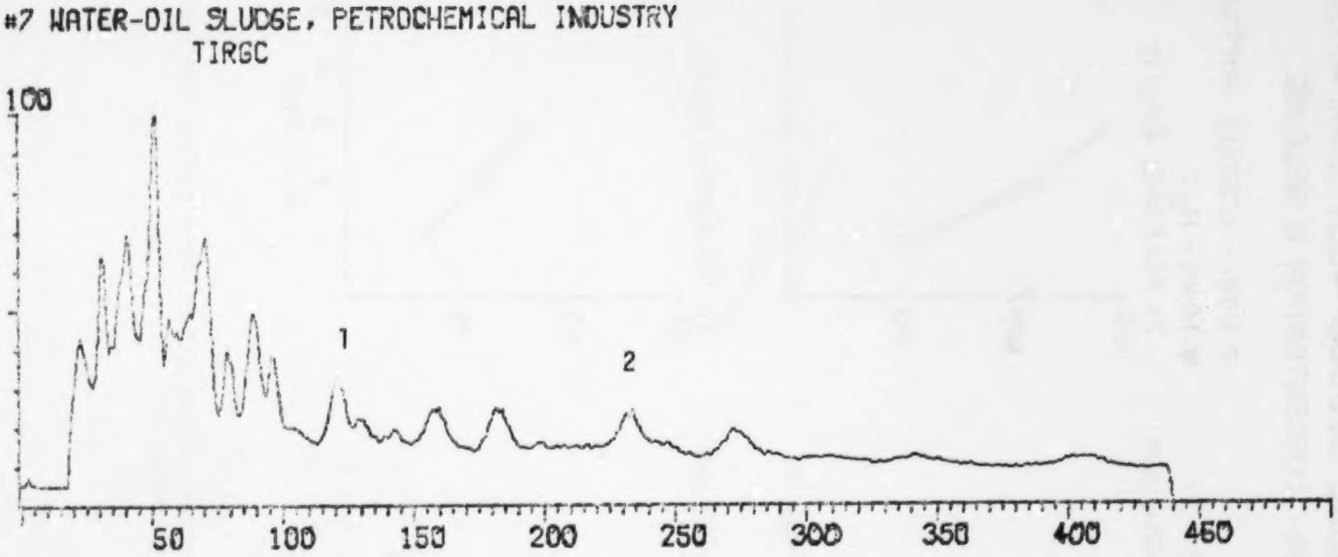


Figure 64. Zn and Pb concentration and release curves for Petrochemical Sludge, test comparison.



1. Hexadecane; 2. napthalene.

(See Figures A-13 and A-14 for additional GC-MS results.)

Figure 65. Total ion reconstructed gas chromatogram of Petrochemical Sludge, hexane extract.

TABLE 25. GRAIN PROCESSING LIPIDS AND FATS WASTE: DESCRIPTION AND SUMMARY OF RESULTS

Waste Number 8, ECHO, Inc.

Description: Solid, hard fat

Analysis:

ECHO: pH - 7.8, suspended solids - 18.75%, Ash - 11.4%, Zn - 11.4 mg/l, Cu - 0.40 mg/l, Pb - .01 mg/l, Cr - 1.3 mg/l, Cd - 0.3 mg/l

Wisconsin: 52% volatile at 105°C for 24 hours

Organics: Not analyzed

Trace Metals of Interest: Zn, Cr

Sample Preparation: Sampled directly

(continued)

TABLE 25 (continued)

Maximum Concentration and Release

	Na	K	Mg	Zn	Pb	Cr*
Concentration, mg/l						
Acid leachates						
SLT proc. C, SL		12.5	95.	2.3	.4	b.d.
SLT proc. R, SL		11.0	28.	2.2	.4	
Minn.		1.1	8.7	.74	.5	
H_2O leachates						
SLT proc. C	6.2	4.5	5.0	0	.2	
SLT proc. R	2.9	7.1	1.1	0	0	
IUCS	24.5	1.5	14.5	0	0	
Minn.	1.4	.15	.4	0	0	
Release, mg/kg						
Acid leachates						
SLT proc. R, SL		137.	570.	49.	9.	
Minn.		44.	348.	30.	18.	
H_2O leachates						
SLT proc. R	60.	78.	30.5	0	0	
IUCS	163.	11.9	165.	0	0	
Minn.	56.	6.	15.	0	0	

*Cr below detection.

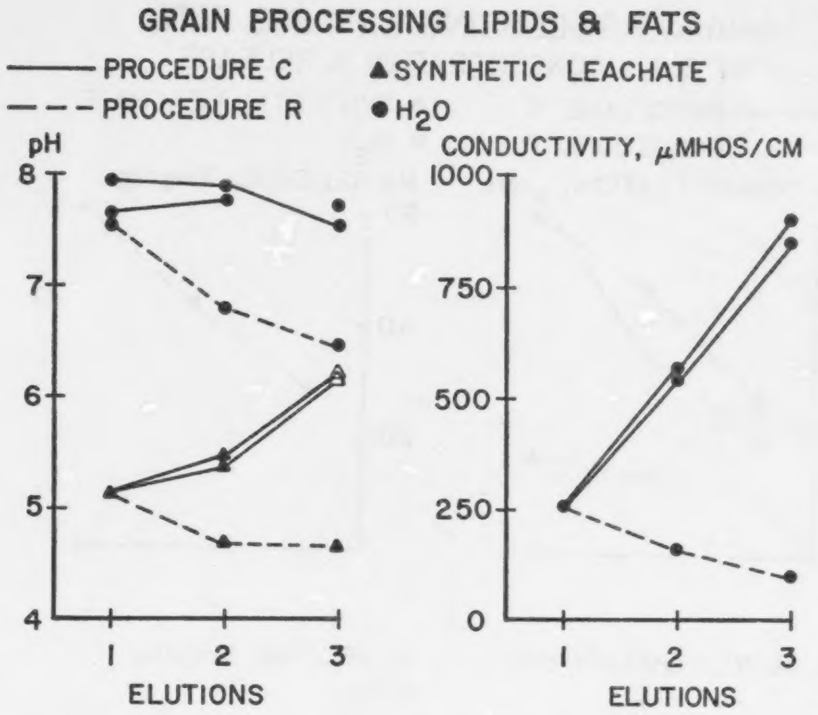


Figure 66. pH and specific conductance curves for Grain Processing Lipids and Fats, SLT.

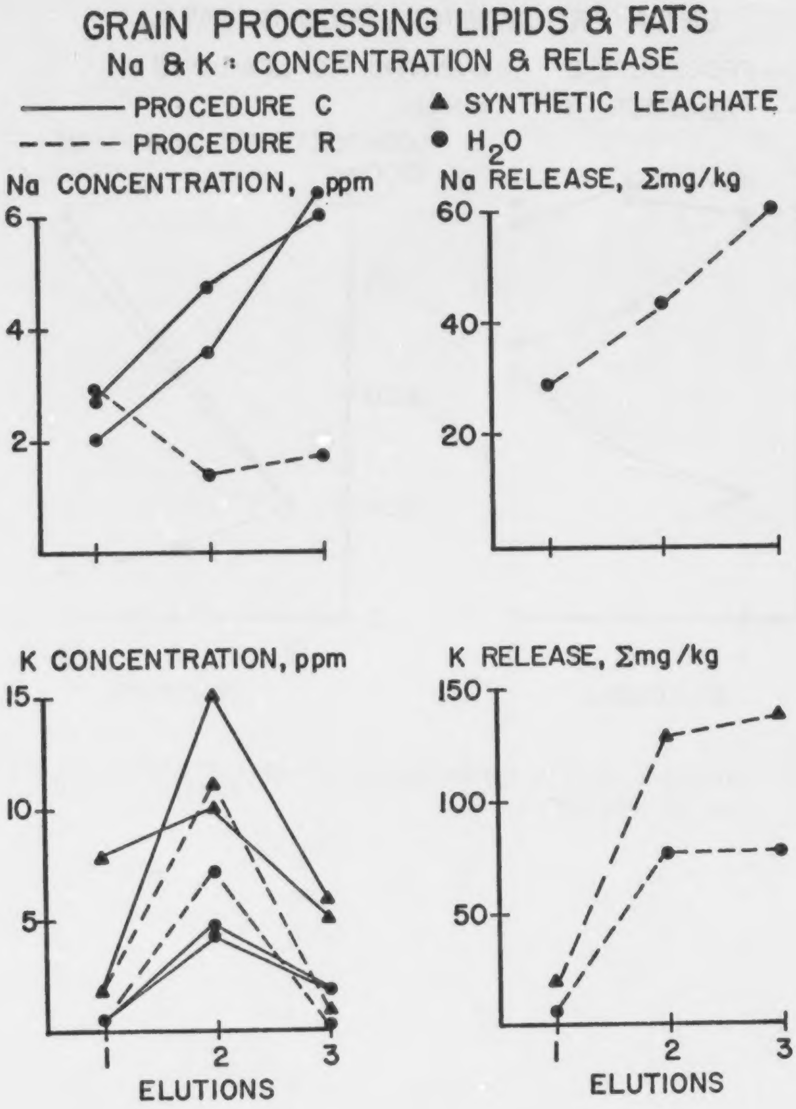


Figure 67. Na and K concentration and release curves for Grain Processing Lipids and Fats, SLT.

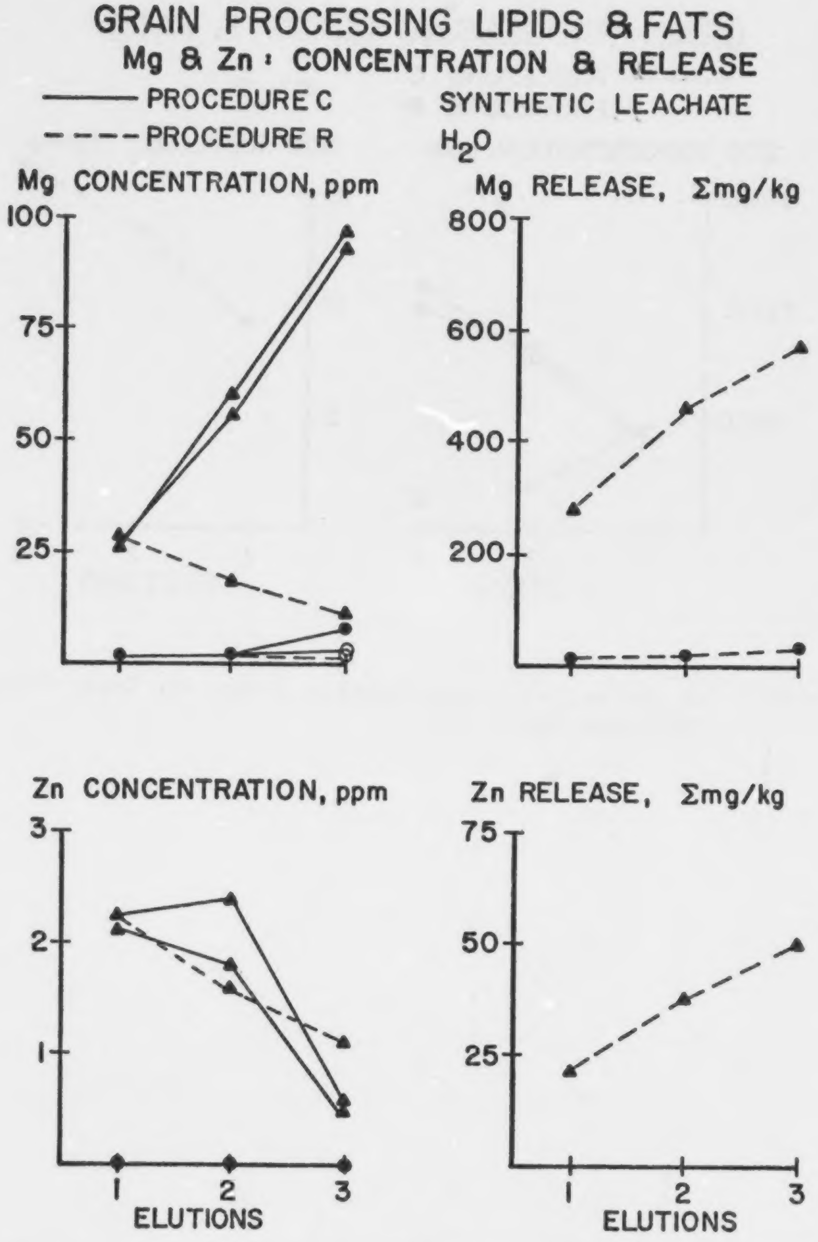


Figure 68. Mg and Zn concentration and release curves for Grain Processing Lipids and Fats, SLT.

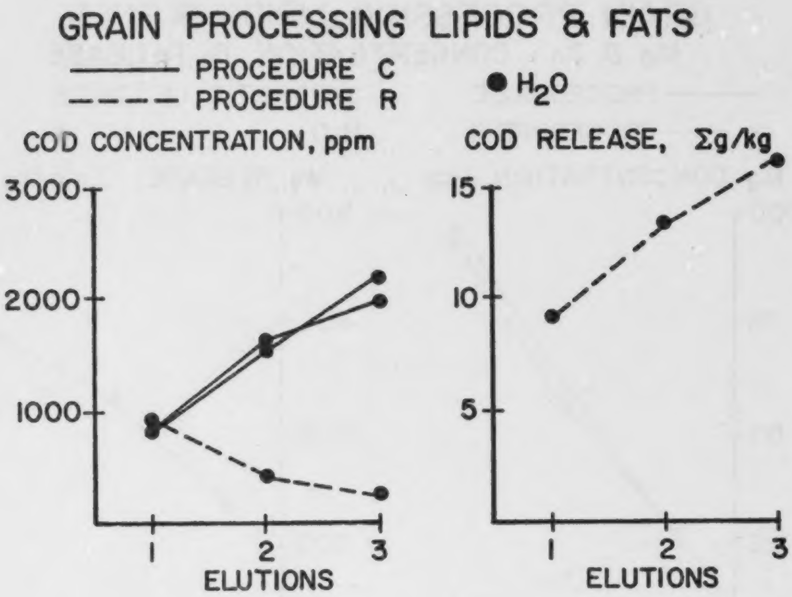


Figure 69. COD concentration and release curves for Grain Processing Lipids and Fats, SLT.

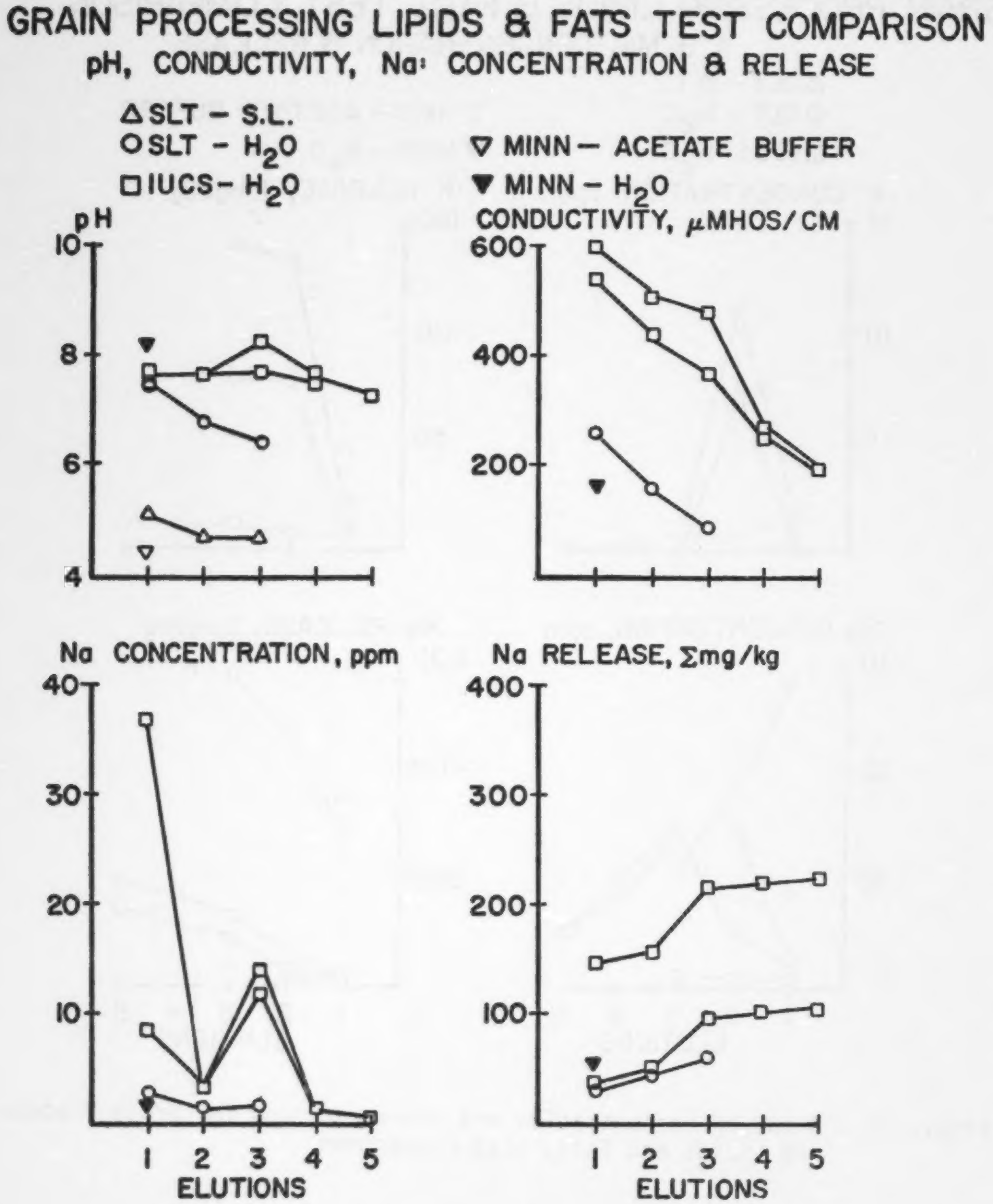


Figure 70. pH, specific conductance, and Na concentration and release curves for Grain Processing Lipids and Fats, test comparison.

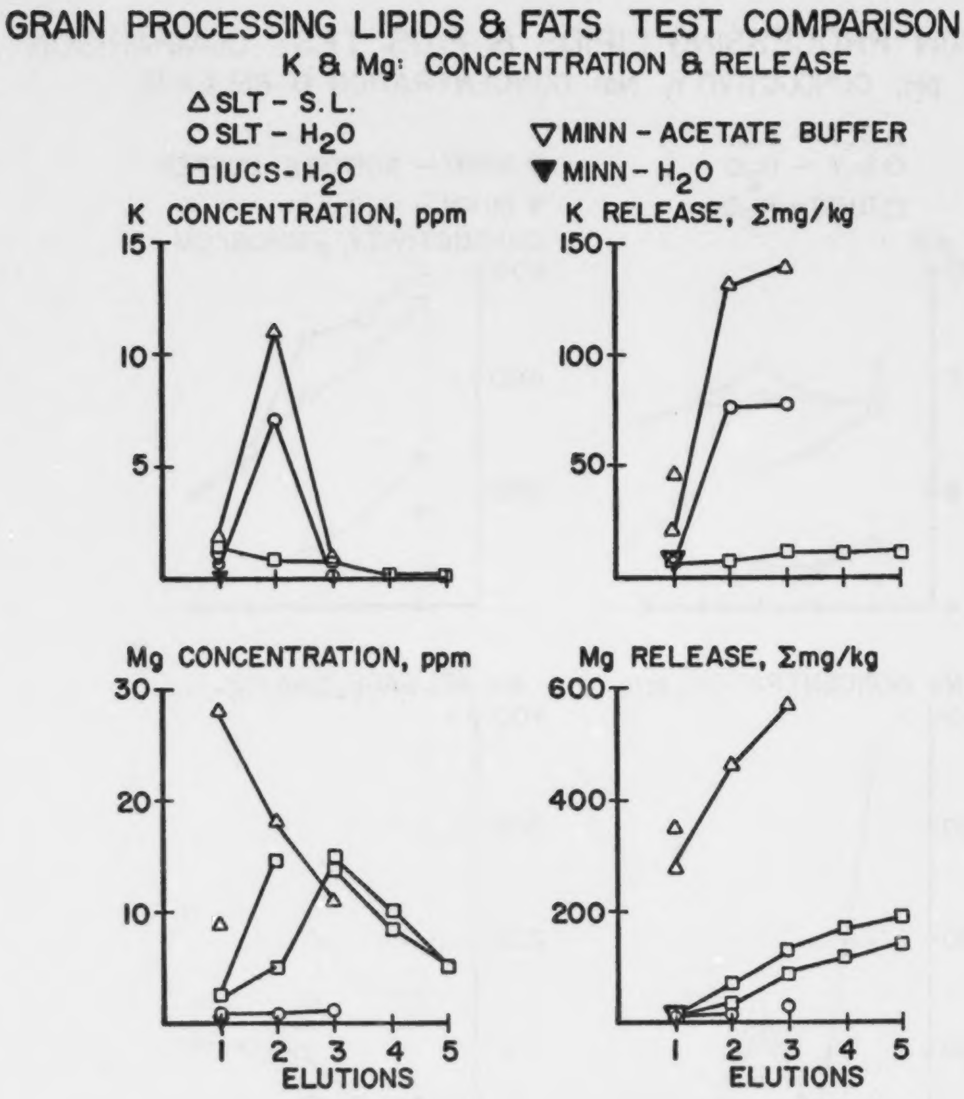


Figure 71. K and Mg concentration and release curves for Grain Processing Lipids and Fats, test comparison.

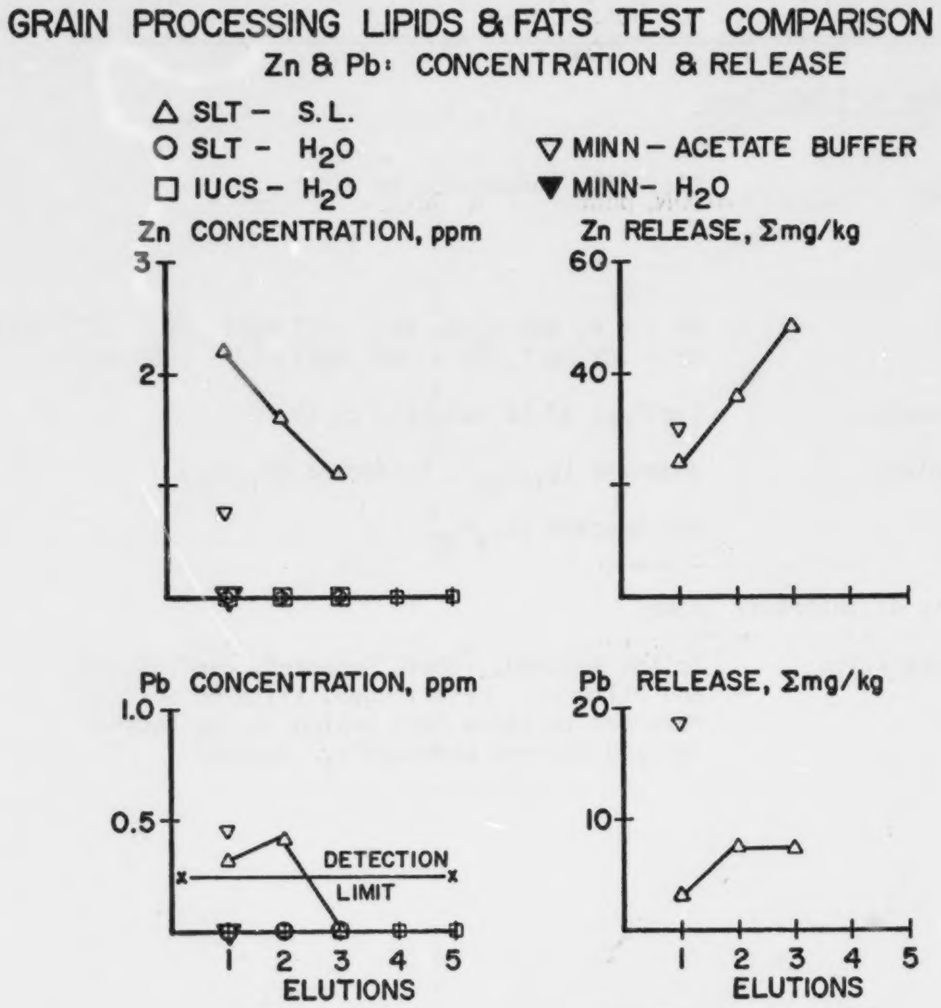


Figure 72. Zn and Pb concentration and release curves for Grain Processing Lipids and Fats, test comparison.

TABLE 26. FOOD INDUSTRY CLAY WASTE: DESCRIPTION AND SUMMARY OF RESULTS

Waste Number 9, ECHO, Inc.

Description:	Clay-like suspension in water
Analysis:	
ECHO:	pH - 6.6, Ash < 1%, Zn - .011 mg/l, Pb - .001 mg/l, Cr - .02 mg/l, Cu - .001 mg/l, Cd - .003 mg/l
Wisconsin:	(solids) 37.1% volatile at 103°C
Organics:	dodecane ($C_{12}H_{26}$), tridecane ($C_{13}H_{38}$), tetradecane ($C_{14}H_{30}$)
Metals of Interest:	None
Sample Preparation:	Solids settled; liquid decanted, centrifuged and filtered. Centrifuged, filtered solids returned to those left behind in the decanting and stirred thoroughly. Sampled.

(continued)

TABLE 26 (continued)

Maximum Concentration and Release

Concentration, mg/l

Acid leachates	Na	K	Mg	Zn	Pb	COD
SLT proc. C, SL		12	27	1.8	.95	
SLT proc. R, SL		6	22	2.0	3.8	
Minn.		2.6	57	1.5	6.5	
H_2O leachates						
SLT proc. C	22	2.7	9.0	0	0	340
SLT proc. R	5.7	.8	2.8	0	0	190
IUCS	15	4.6	5.1	0	0	128
Minn.	2	.3	.7	0	0	4

Release, mg/kg

Acid leachates	Na	K	Mg	Zn	Pb	COD
SLT proc. R, SL		94	570	51	56	
Minn.		104	2280	60	260	
H_2O leachates						
SLT proc. R	116	12	41	0	0	3340
IUCS	124	29	49	0	0	1800
Minn.	80	13	29	0	0	160

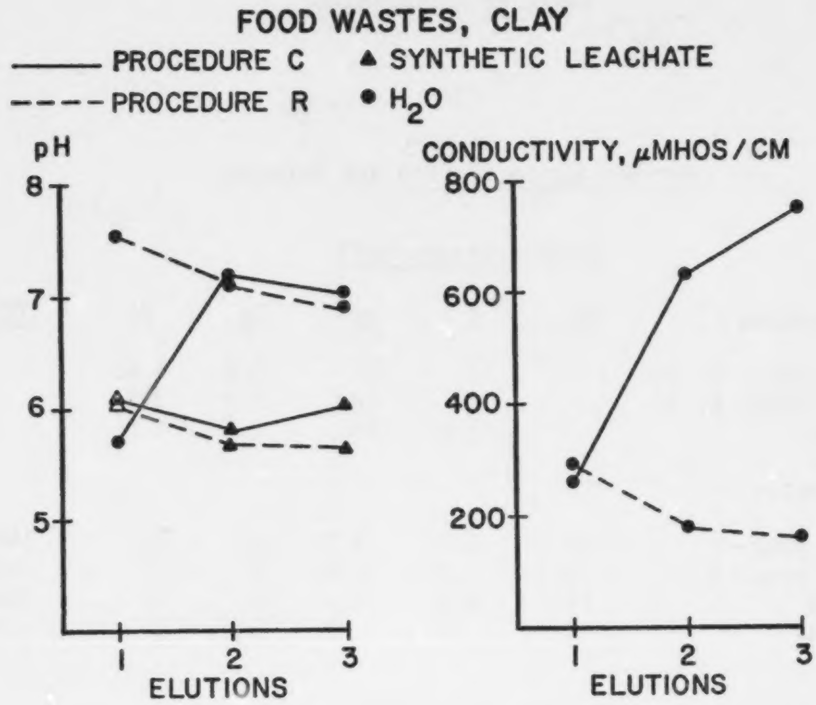


Figure 73. pH and specific conductance curves for Food Wastes, Clay, SLT.

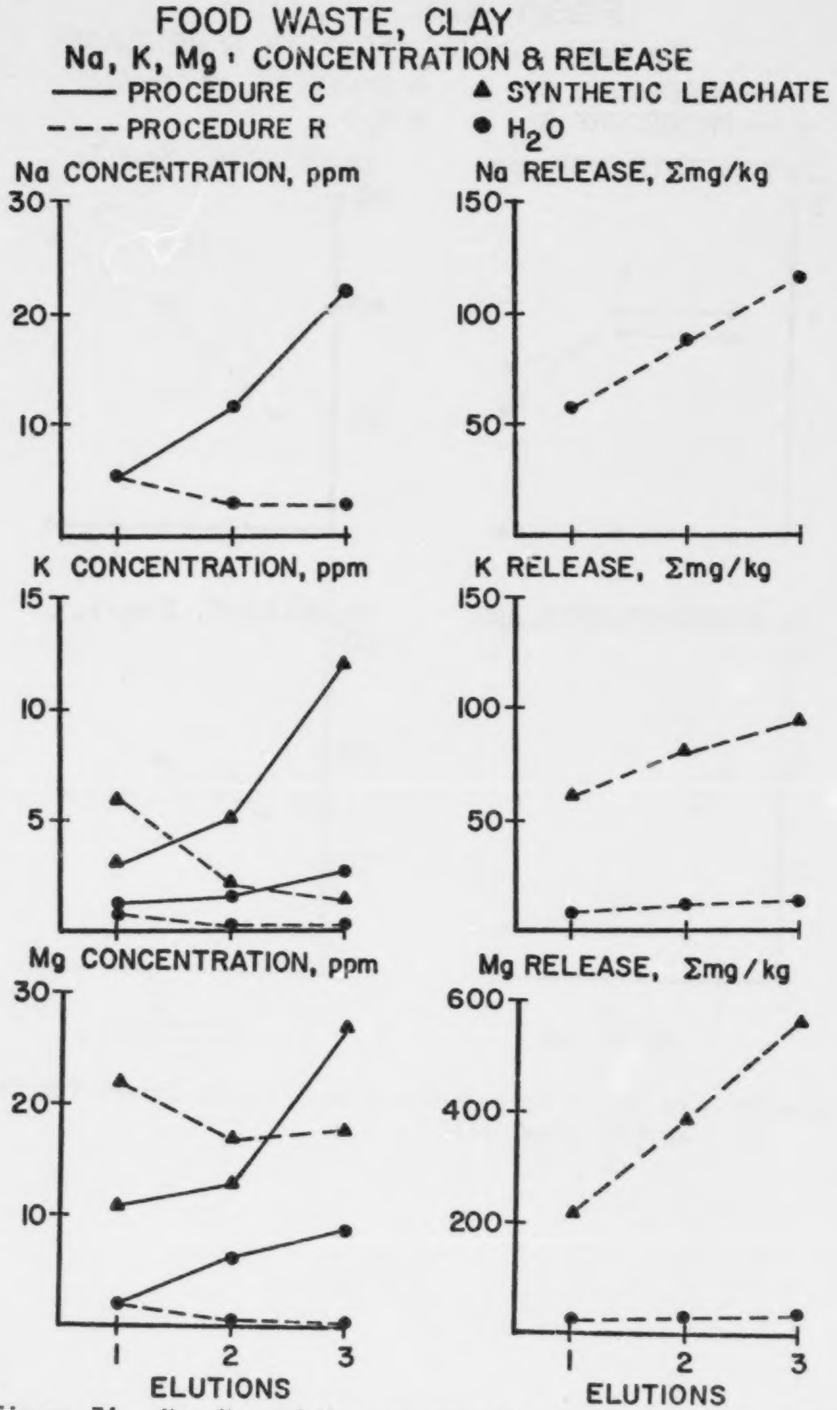


Figure 74. Na, K, and Mg concentration and release curves for Food Wastes, Clay, SLT.

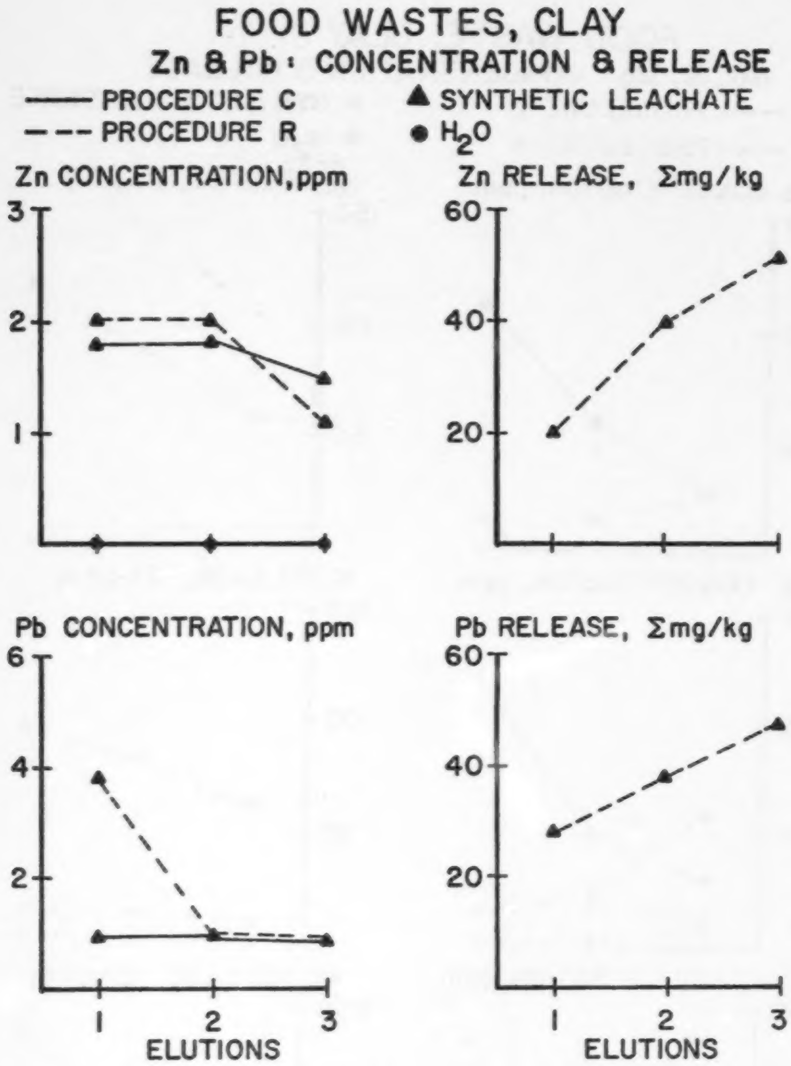


Figure 75. Zn and Pb concentration and release curves for Food Wastes, Clay, SLT.

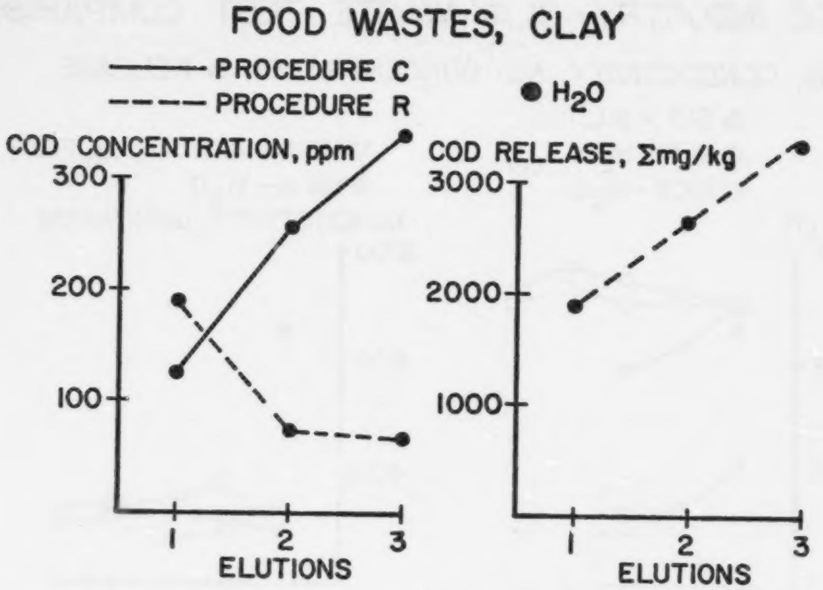


Figure 76. COD concentration and release curves for Food Wastes, Clay, SLT.

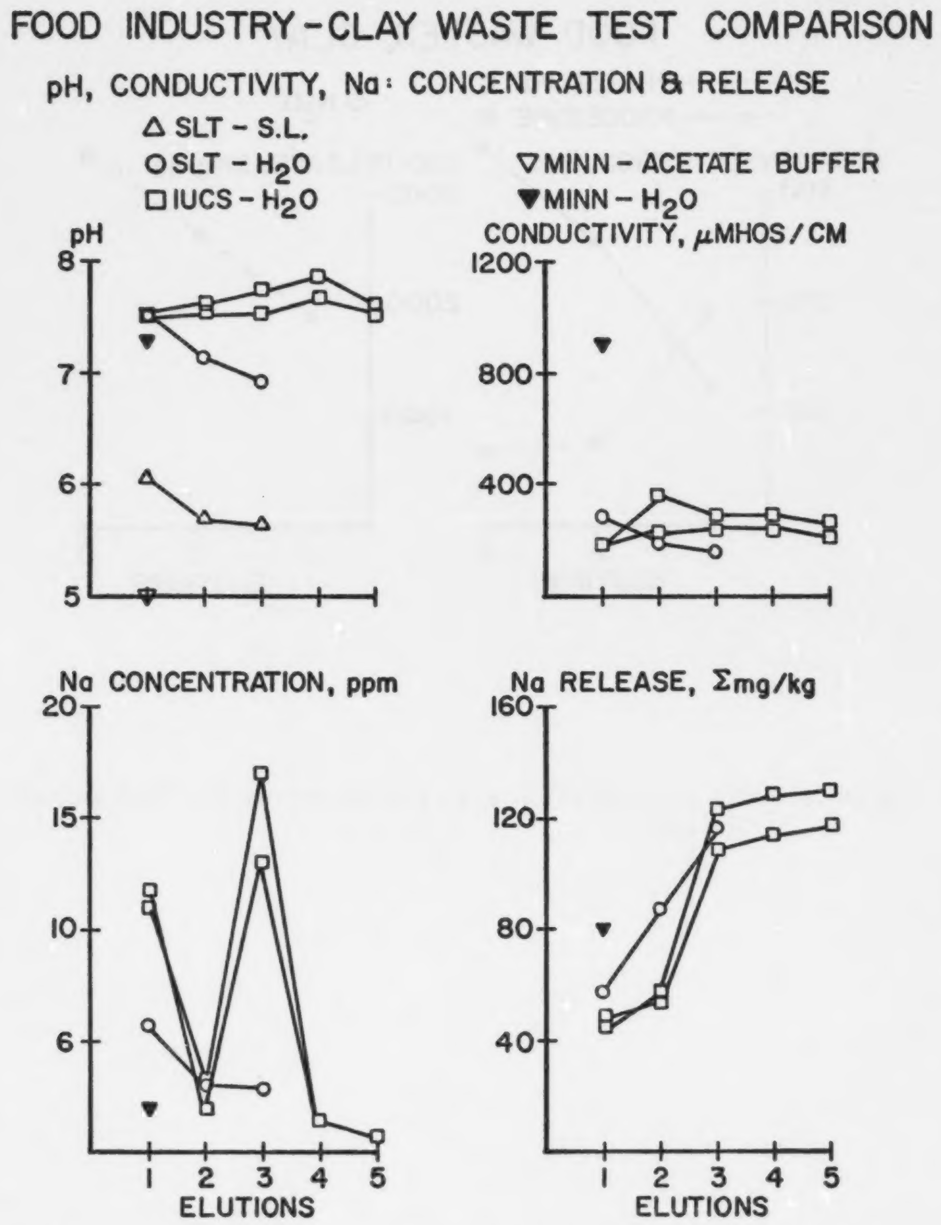


Figure 77. pH, specific conductance, and Na concentration and release curves for Food Wastes, Clay, test comparison.

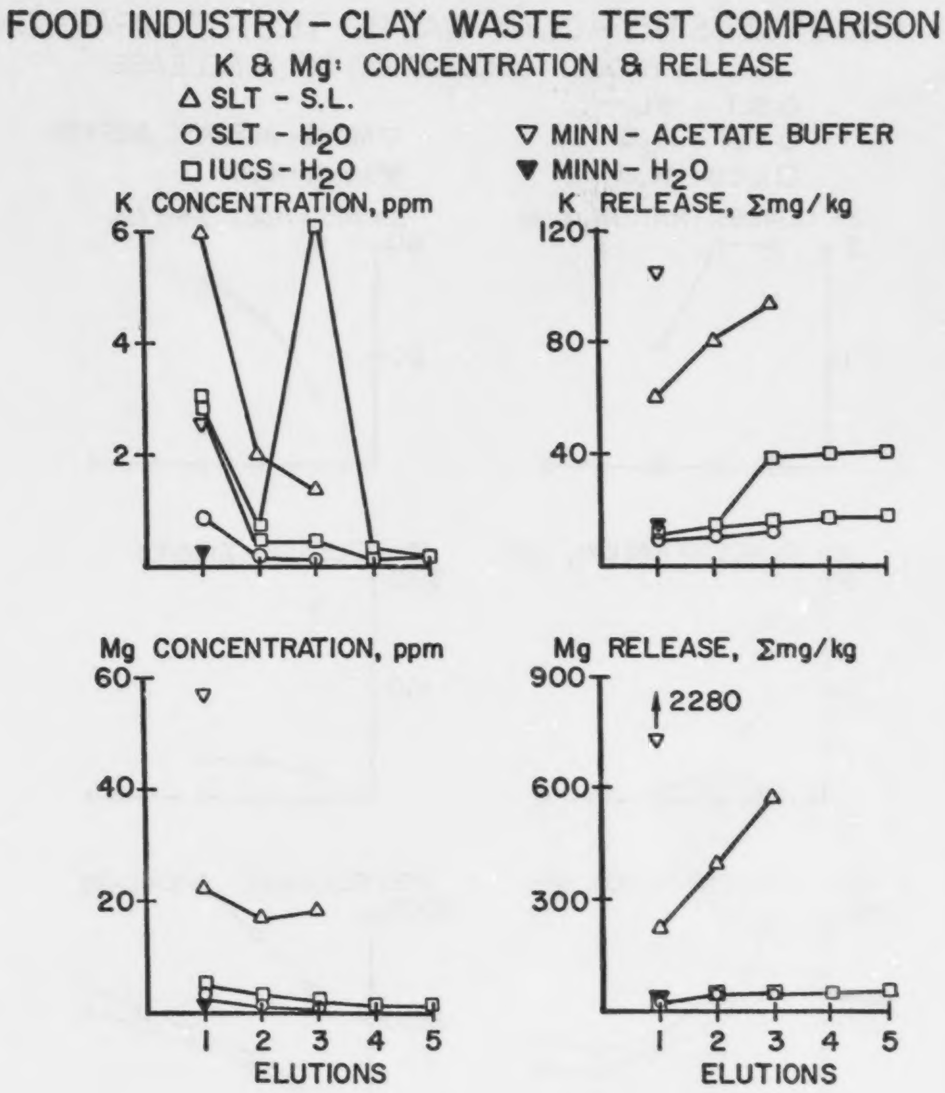


Figure 78. K and Mg concentration and release curves for Food Wastes, Clay, SLT.

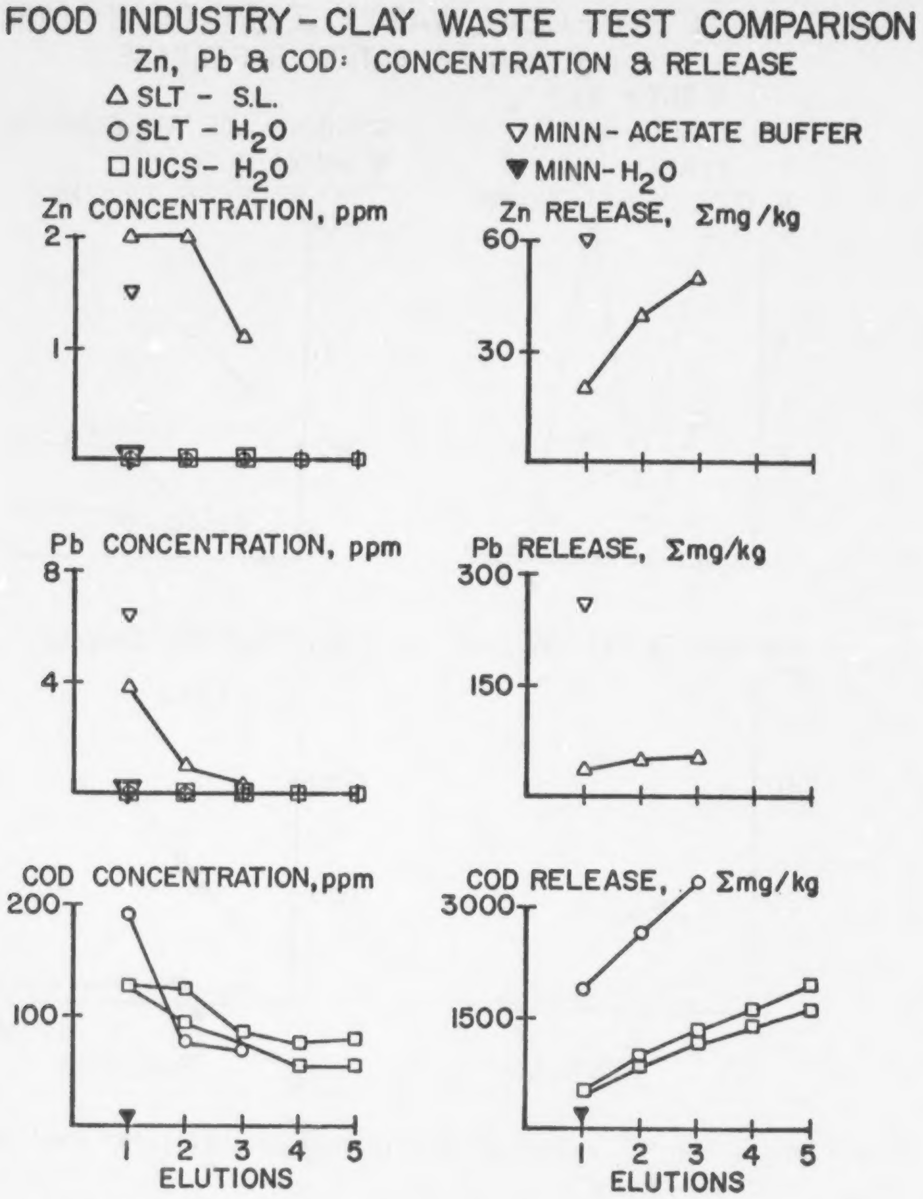
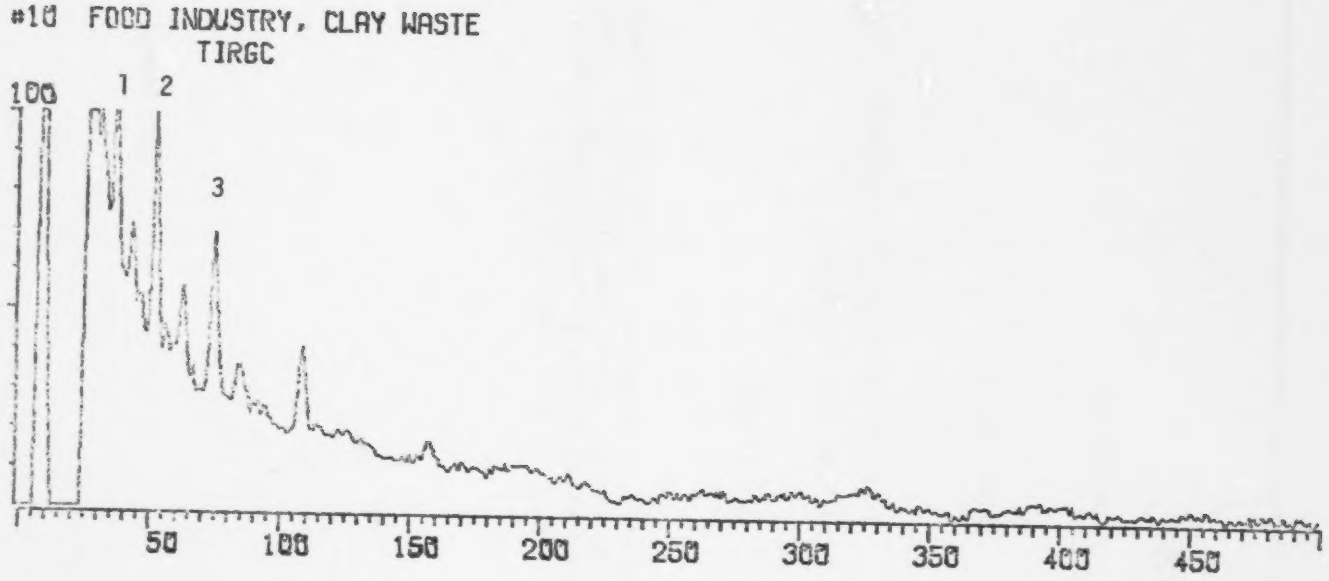


Figure 79. Zn, Pb, and COD concentration and release curves for Food Wastes, Clay, test comparison.



1. dodecane; 2. tridecane; 3. tetradecane.
(See Figures A-15, A-16, and A-17 for additional GC-MS results.)

Figure 80. Total ion reconstructed gas chromatogram for Food Wastes, Clay, hexane extract.

TABLE 27. MARBLE WASH: DESCRIPTION AND SUMMARY OF RESULTS

Waste Number 10, ECHO, Inc.

Description: Suspension

Analysis:

- ECHO: Unavailable.
- Wisconsin:
- Organics: Tetradecane ($C_{14}H_{30}$), hexadecane ($C_{16}H_{34}$), Octadecane ($C_{18}H_{38}$).
- Trace Metals of Interest: Unavailable.

Sample Preparation:

Similar to food industry, clay waste. Solids were allowed to settle. The liquid was decanted, centrifuged and filtered, and the solids removed from the decanted liquid and mixed thoroughly with the original solids. The solids were then sampled directly.

(continued)

TABLE 27 (continued)

Maximum Concentration and Release

	Concentration, mg/l				
Acid leachates	Na	K	Mg	Pb	COD
SLT proc. C, SL		20.0	109	.60	
SLT proc. R, SL		10.0	60	.63	
Minn.		1.1	77	3.5	
H_2O leachates					
SLT proc. C.	24.0	4.4	21	0	142
SLT proc. R	8.9	1.7	10.0	0	128
IUCS	22.5	3.9	.47	0	116
Minn.	3.1	0.6	1.8	0	72
	Release, mg/kg				
Acid leachates					
SLT proc. R, SL		196	1105	16.6	
Minn.		44	3080	140	
H_2O leachates					
SLT proc. R	127	37	192	0	2230
IUCS	301	45	6.4	0	1576
Minn.	124	26	72	0	2880

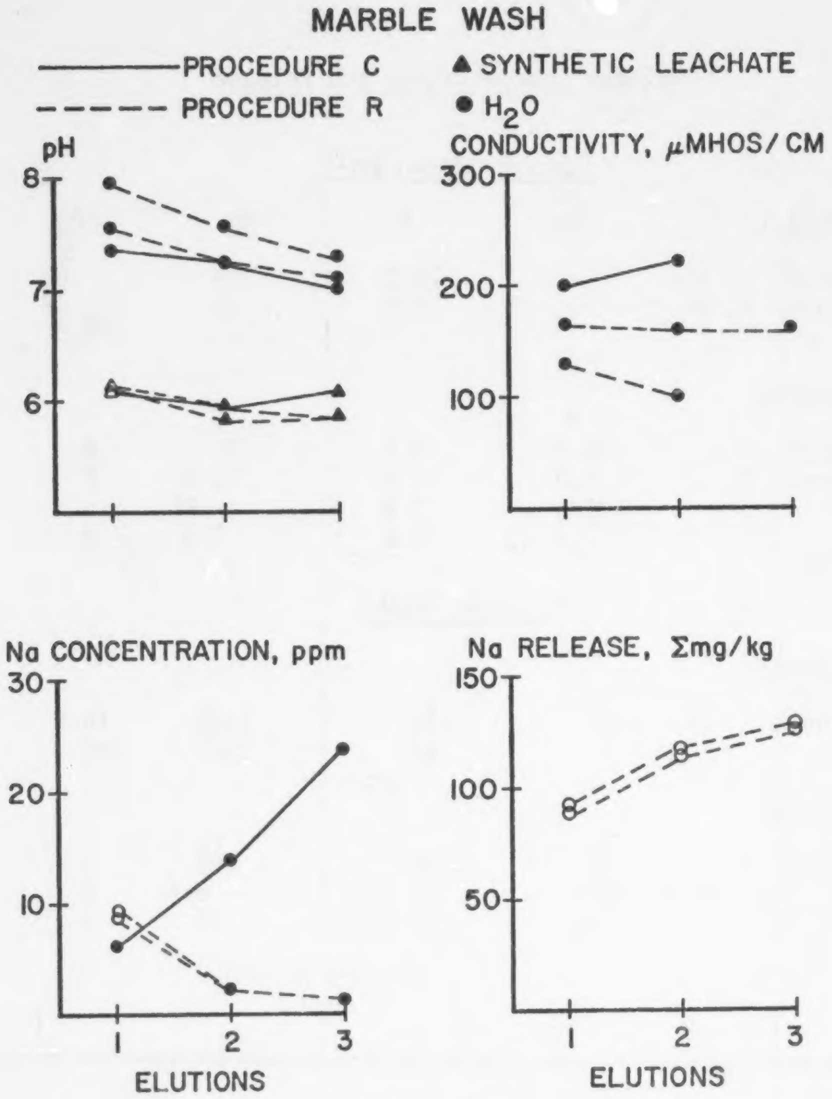


Figure 81. pH, specific conductance, and Na concentration and release curves for Marble Wash, SLT.

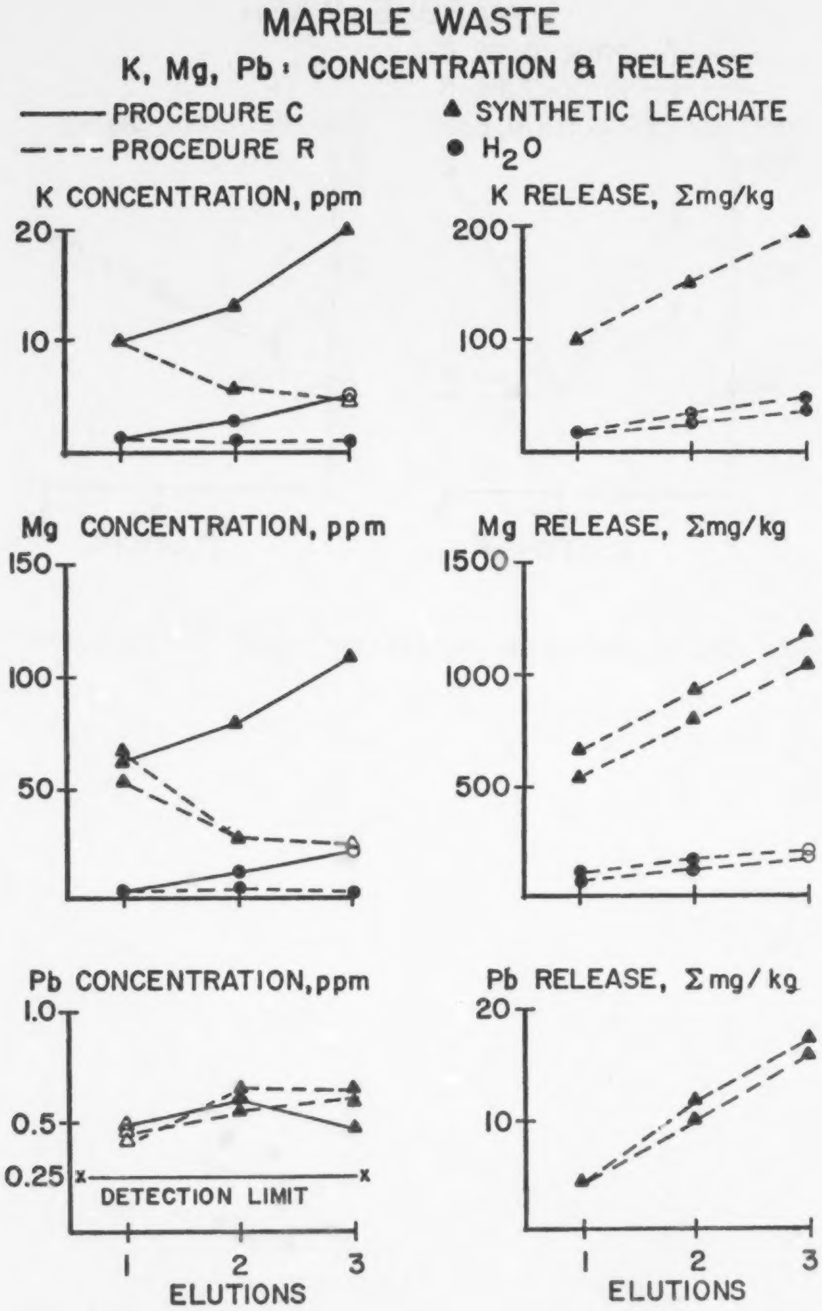


Figure 82. K, Mg, and Pb concentration and release curves for Marble Wash, SLT.

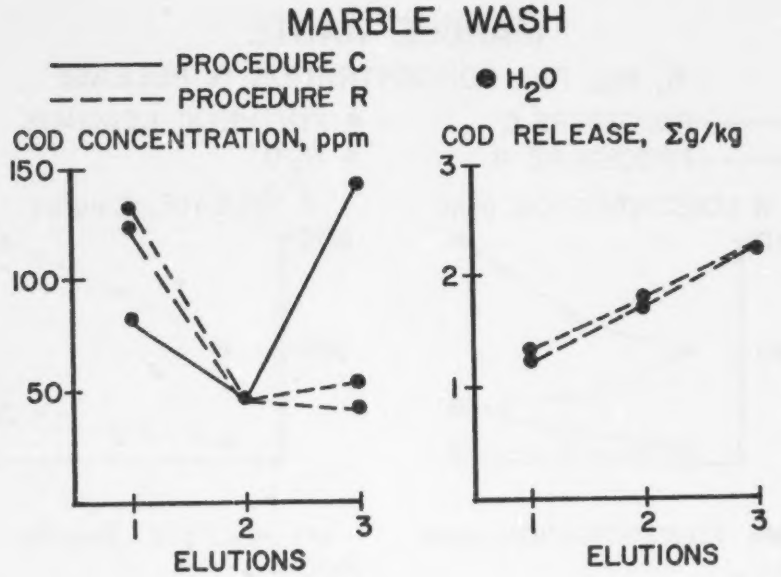


Figure 83. COD concentration and release curves for Marble Wash, SLT.

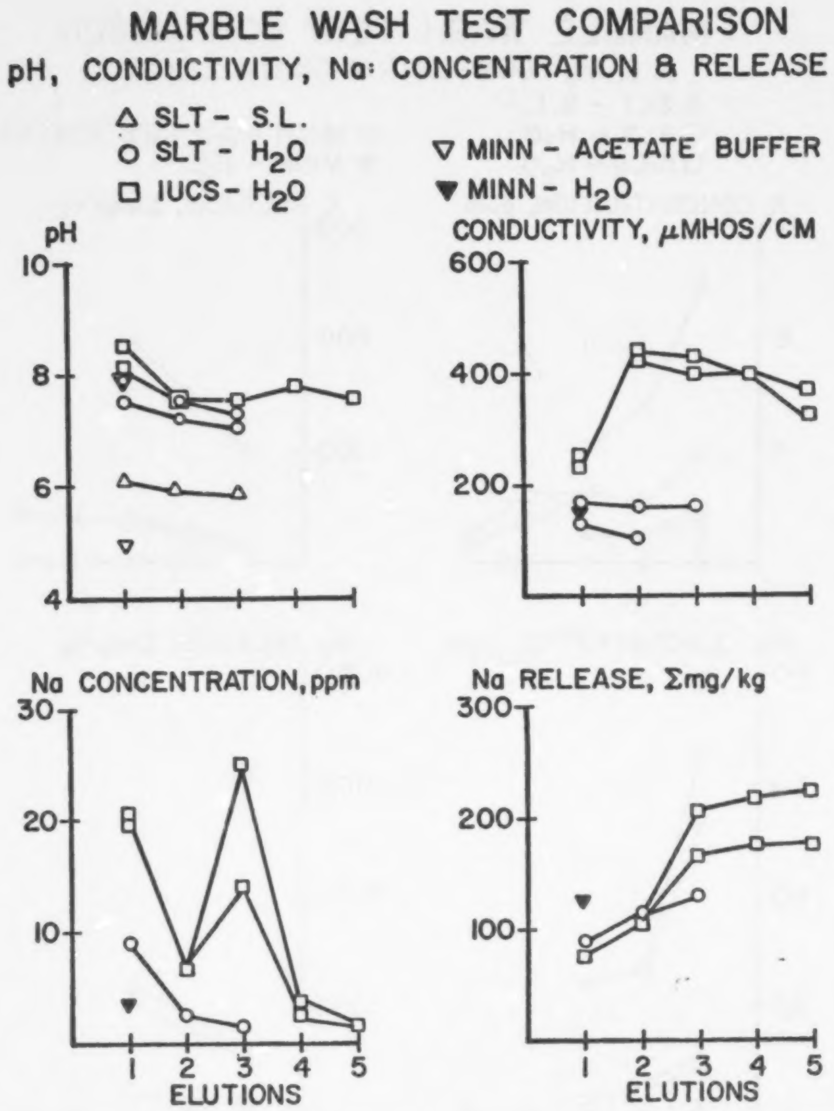


Figure 84. pH, specific conductance, and Na concentration and release curves for Marble Wash, test comparison.

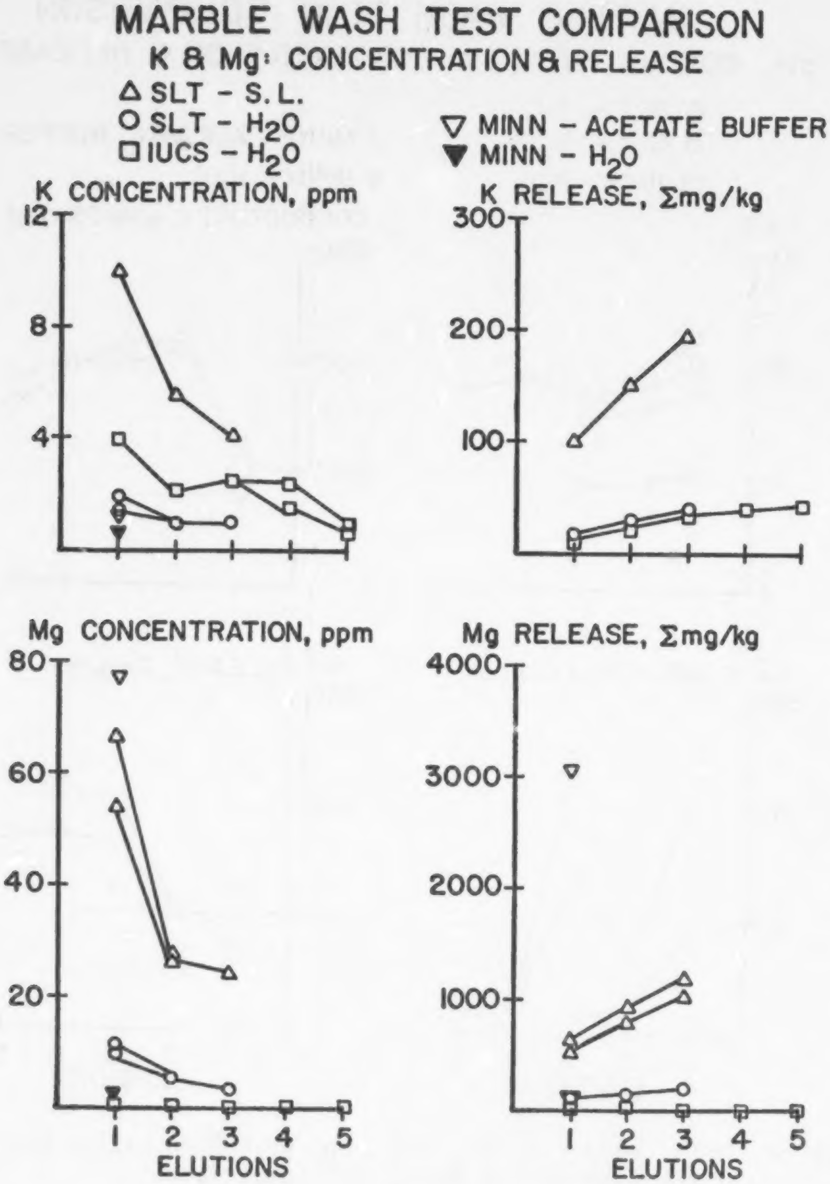


Figure 85. K and Mg concentration and release curves for Marble Wash, test comparison.

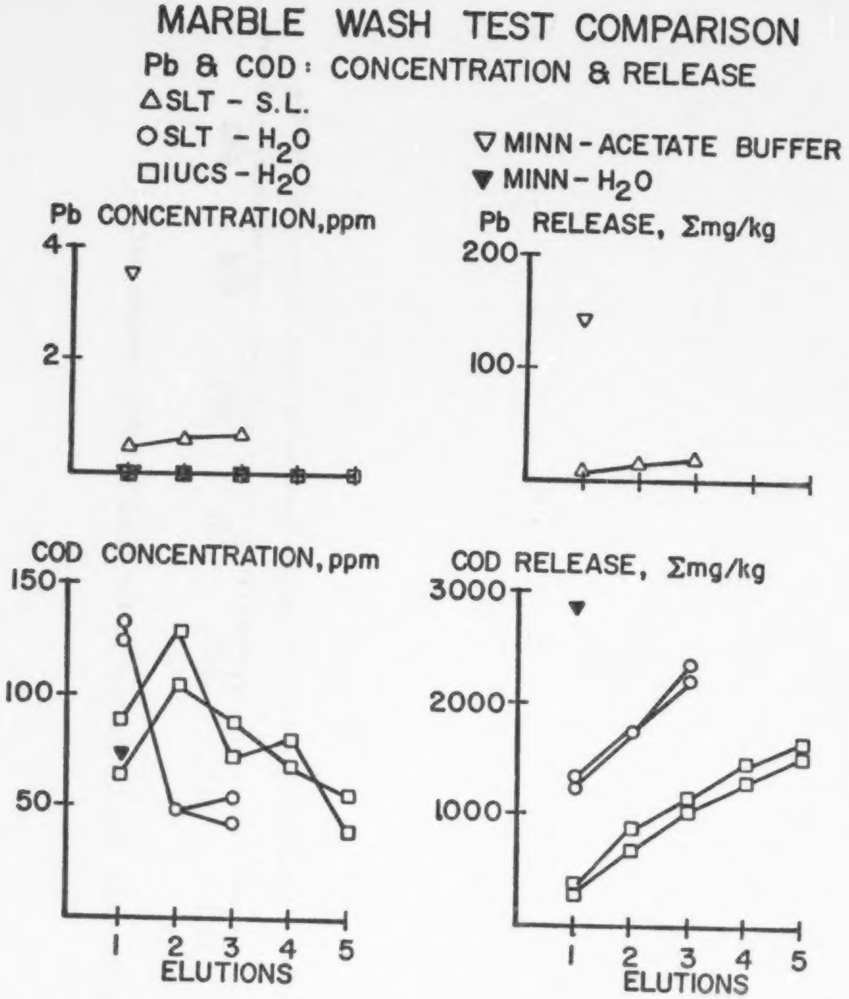


Figure 86. Pb and COD concentration and release curves for Marble Wash, test comparison.

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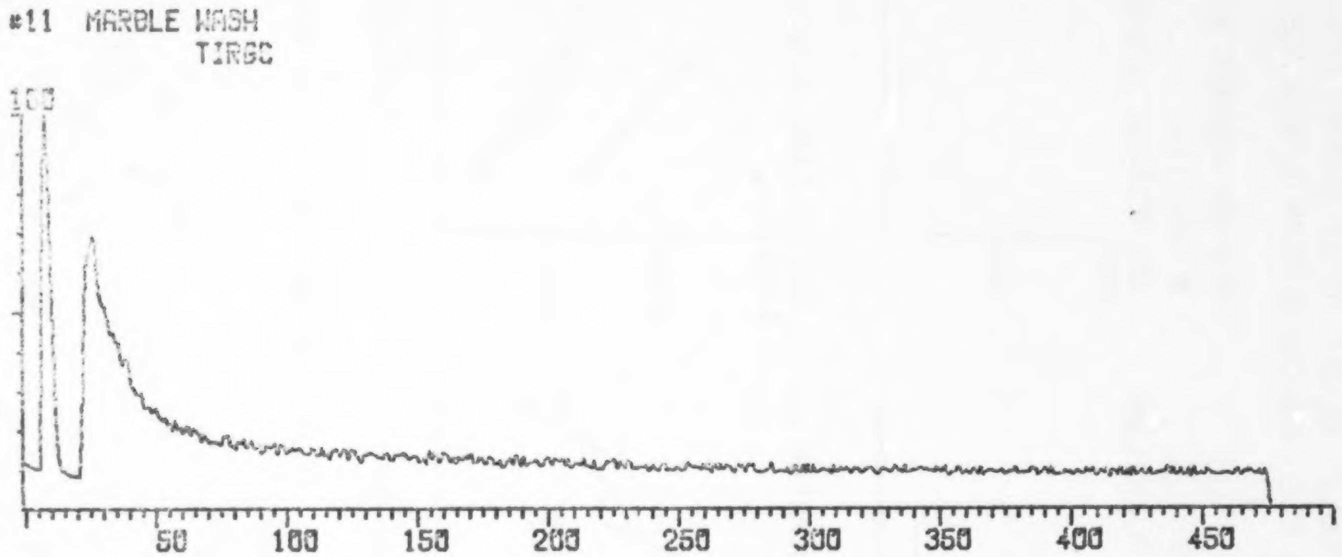

Figure 87. Total ion reconstructed gas chromatogram for Marble Wash, hexane extract.

TABLE 28. COPPER OXIDE-SODIUM SULFATE SLUDGE ($CuO-Na_2SO_4$ WASTE): DESCRIPTION AND SUMMARY OF RESULTS

Waste Number 11, Chem-Trol

Description:	Generated by large chemical manufacturer. Black, low viscosity liquid containing both fine particulates and large (soft-ball size) translucent crystals. Large crystals had apparently precipitated during shipment, as analysis by Chem-Trol did not mention them.
Analysis:	
Chem-Trol:	Less than 5% solids, sp. gr. 1.28, pH 10.4, phenol 20 ppm, total carbon 200 ppm; total inorganic carbon 50 ppm, Cu 9 ppm.

Sample Preparation:

Liquid decanted and filtered. Solids returned to sample pail. These were stirred to get as homogeneous a sample as possible. A subsample was taken with a large beaker, then the subsample ground in mortar and pestle until the large crystals were broken up. This mixture was filtered, and the solid portion used for analysis.

(continued)

TABLE 28 (continued)

Maximum Concentration and Release

Concentration, mg/l

Acid leachates	Na	K	Mg	Cu	Zn	Fe
SLT proc. C, SL		32.4	3281	2916	7.65	
SLT proc. R, SL		5.2	1970	3120	6.84	
Minn.		4.4	380	1450	3.7	120
H_2O leachates						
SLT proc. C	42000	39	153	0.57	.20	1.55
SLT proc. R	9740	4.30	132	0.38	0	.1
IUCS	23000	24	6.4	0.27	.12	.31
Minn.	4970	3.5	12	.18	0	.18
Release, mg/kg						
Acid leachates						
SLT proc. R, SL		171	4.32×10^4	1.04×10^5	155	
Minn		185	1.53×10^4	7.42×10^4	155	5.1×10^3
H_2O leachates						
SLT proc. R	2.20×10^5	90	6734	6.9	.6	3.8
IUCS	1.70×10^5	140	104	2.0	.7	2.2
Minn	2.07×10^5	150	616	13.6	2	18

Note that the Na and the Cu and Mg concentration and release test comparison curves were presented earlier as Figures 4 and 1, respectively.

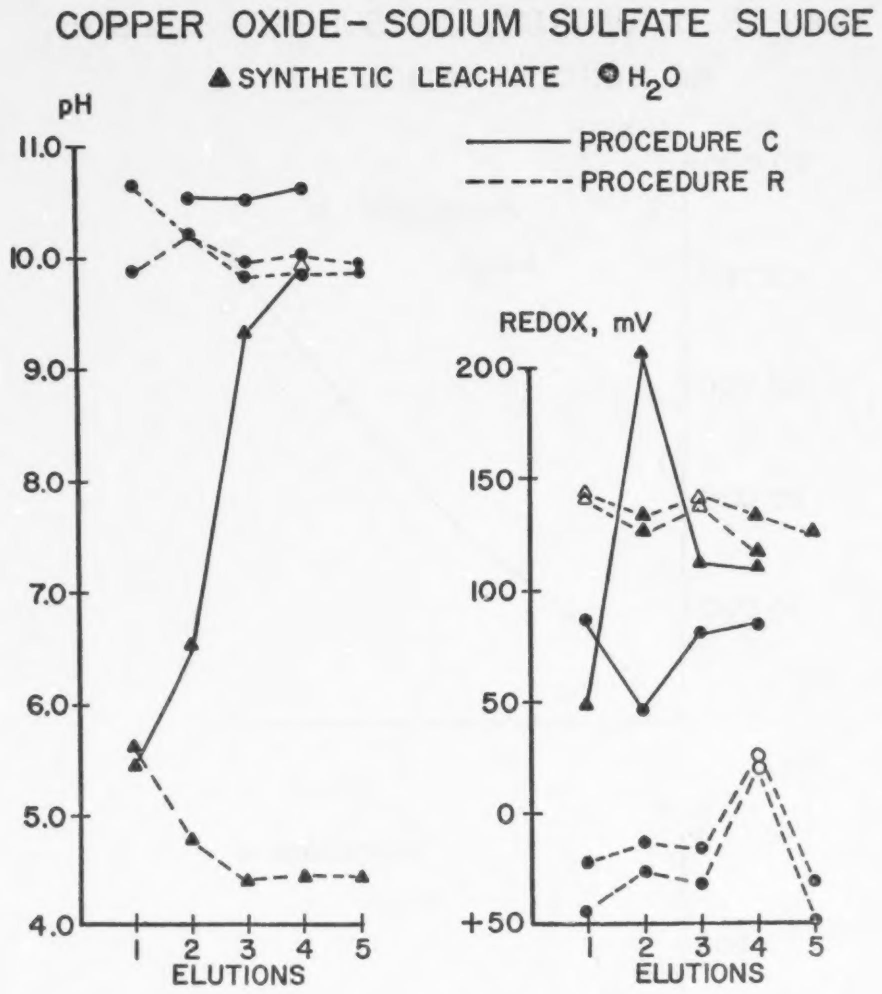

Figure 88. pH and redox curves for CuO-Na_2SO_4 Sludge, SLT.

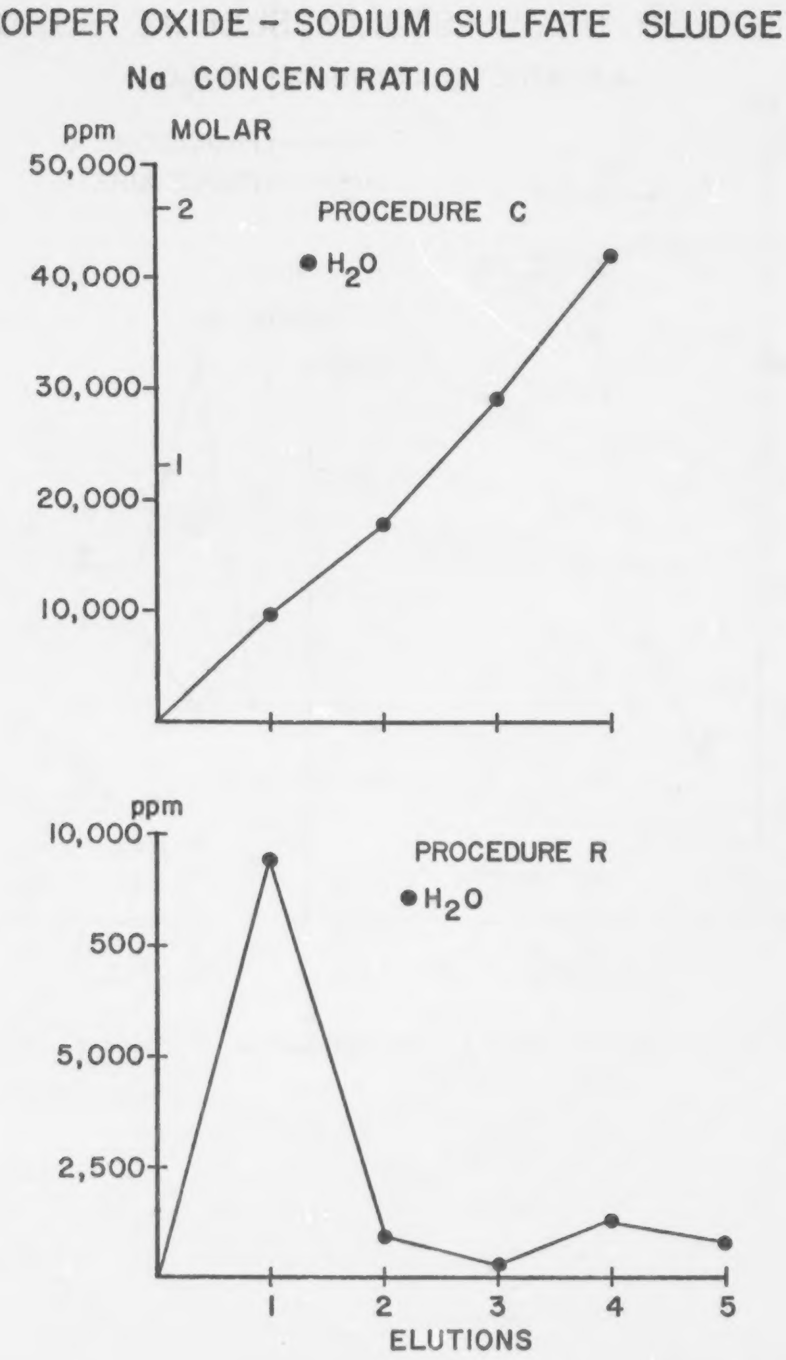

Figure 89. Na concentration curves for CuO-Na_2SO_4 Sludge, SLT.

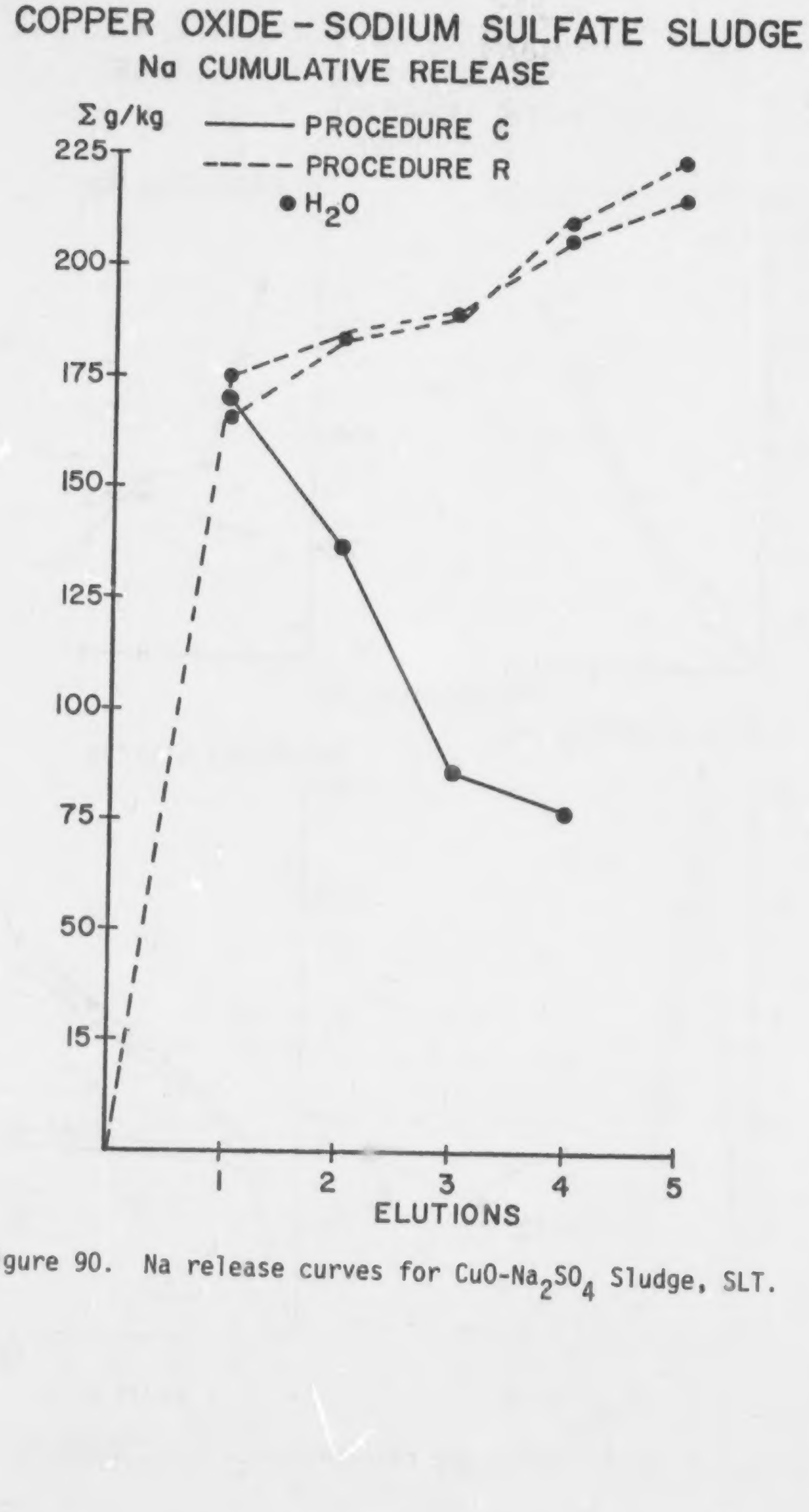

Figure 90. Na release curves for CuO-Na_2SO_4 Sludge, SLT.

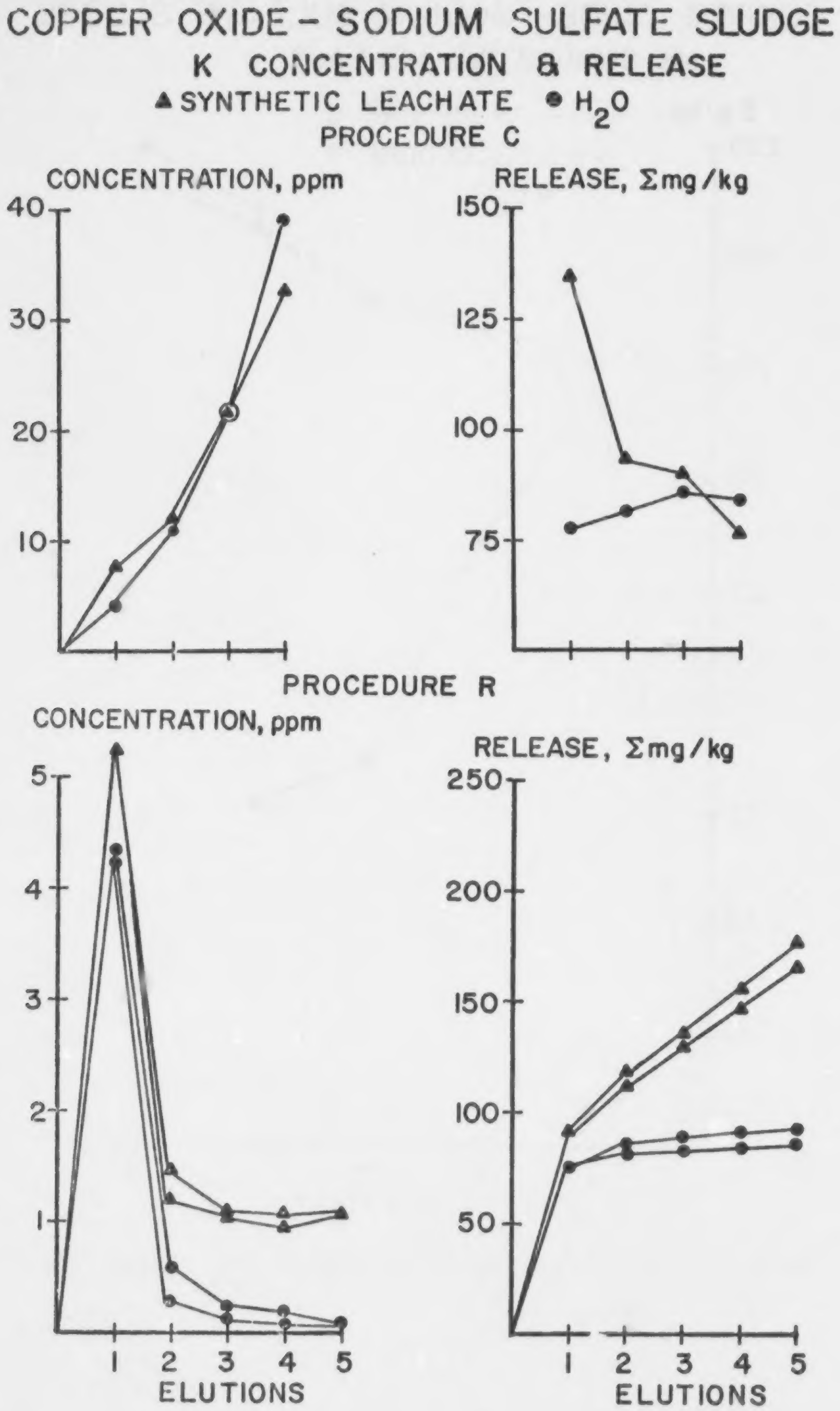

Figure 91. K concentration and release curves for CuO-Na_2SO_4 Sludge, SLT.

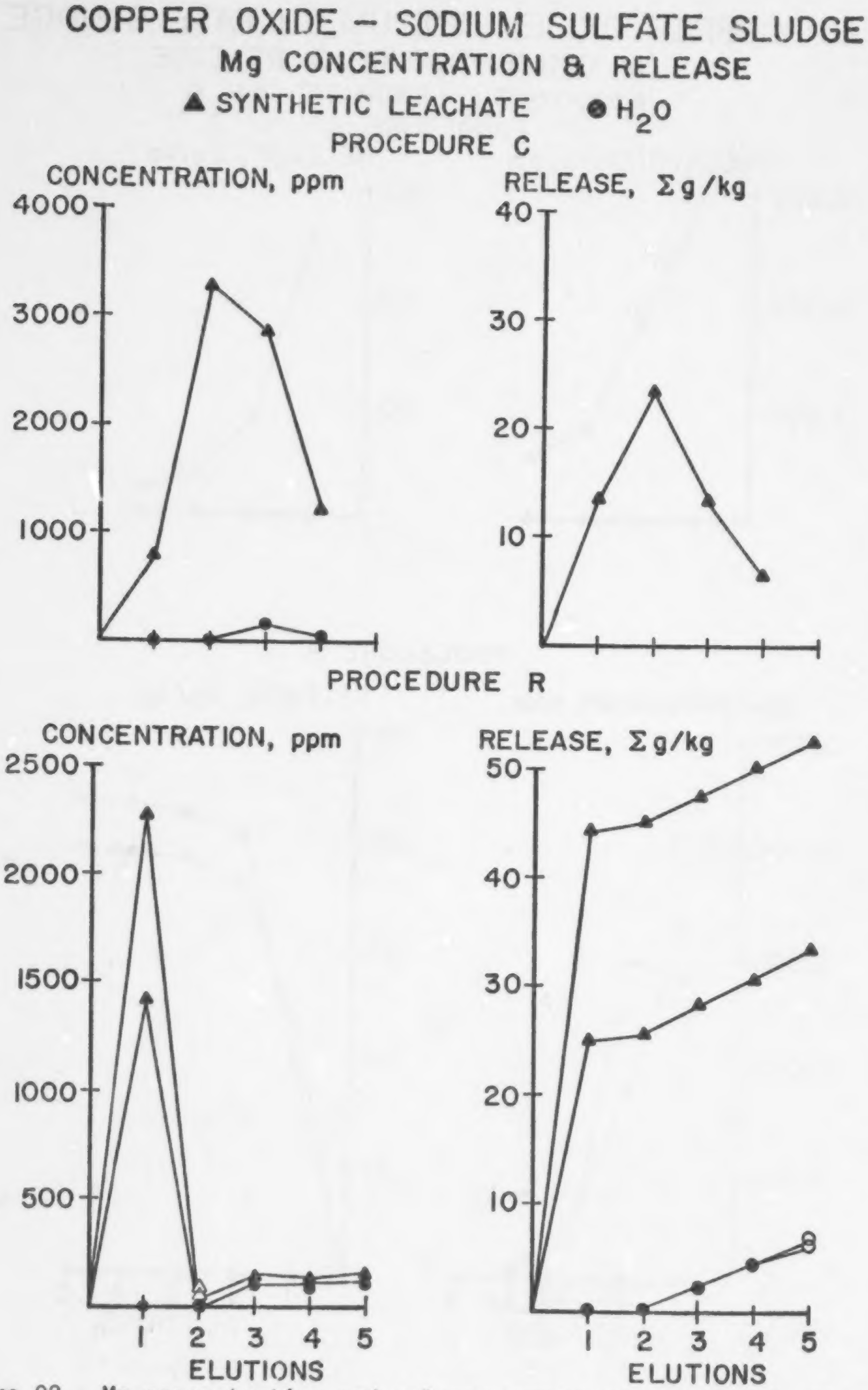

Figure 92. Mg concentration and release curves for CuO-Na_2SO_4 Sludge, SLT.

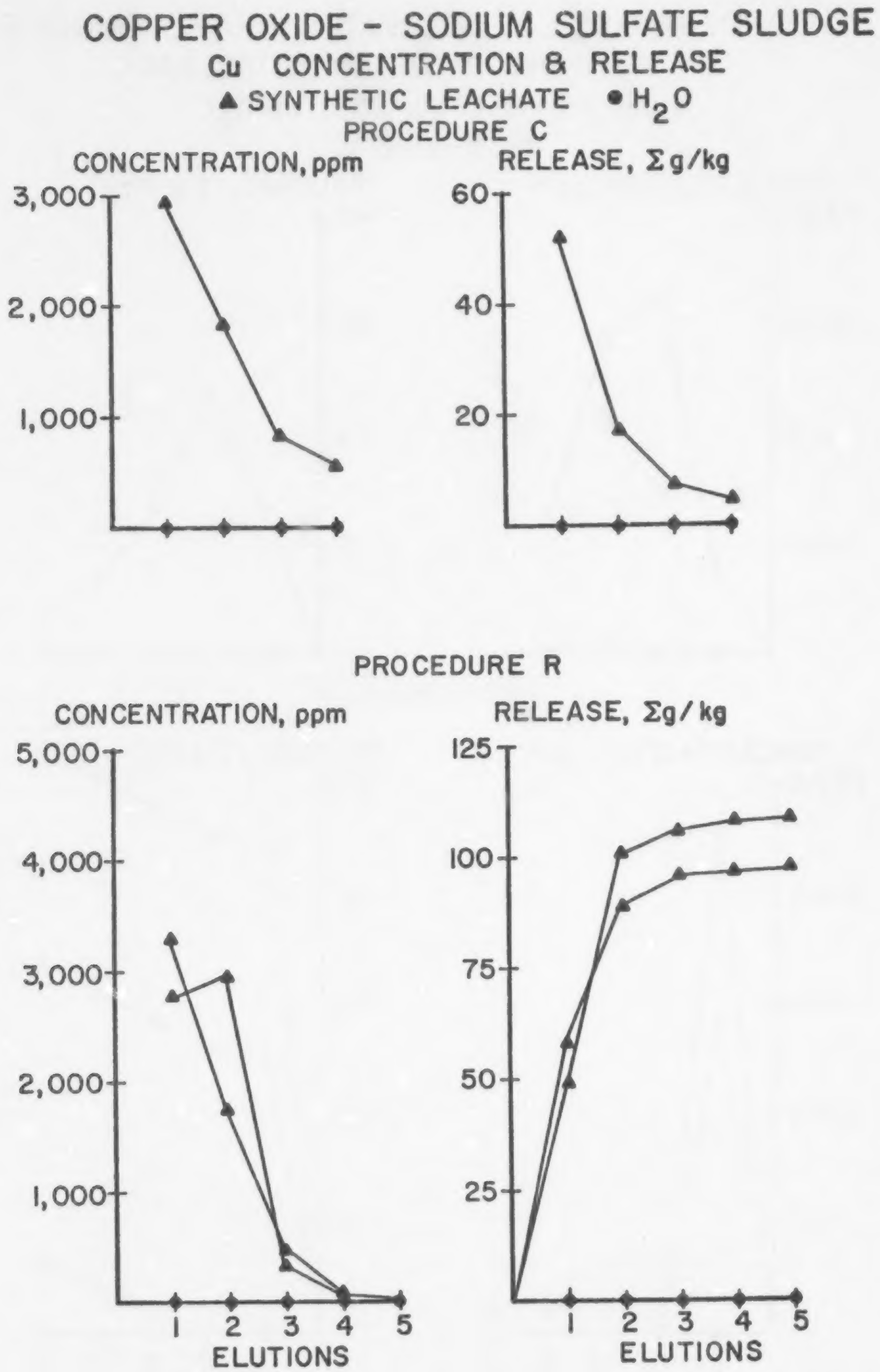

Figure 93. Cu concentration and release curves for CuO-Na_2SO_4 Sludge, SLT.

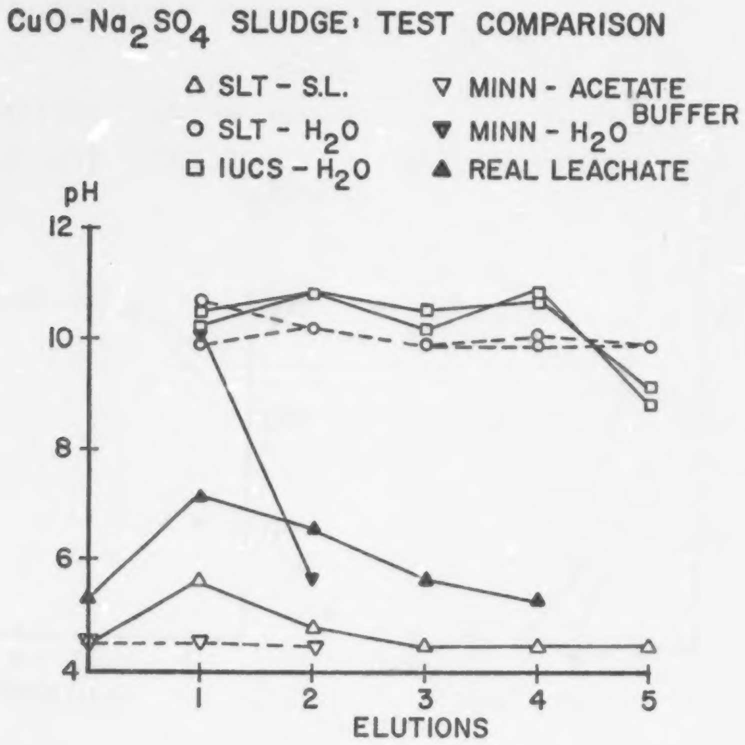

Figure 94. pH curves for CuO-Na_2SO_4 Sludge, test comparison.

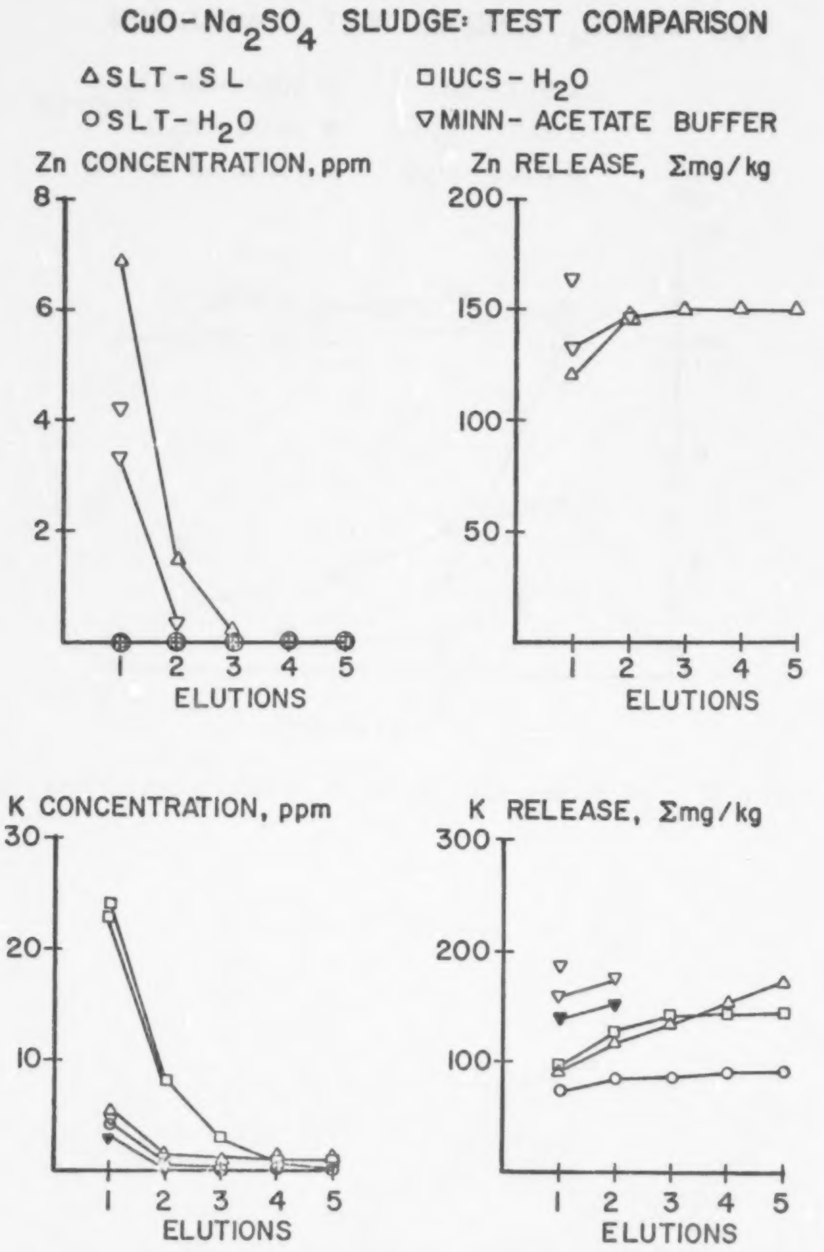

Figure 95. Zn and K concentration and release curves for CuO-Na_2SO_4 Sludge, test comparison.

Discussion

SLT--

This was the most interesting and informative of the wastes. Discussion of each parameter of interest will be done separately.

pH--Distilled water leachates show that the waste is basic, buffering solutions at a pH between 9.9 and 10.7. SL procedure C leachates show the strong basic nature of the waste. By the fourth elution, the pH in the SL leachate was equal to that in the H_2O leachates. Procedure R SL samples show that the basic salt is removed by the third elution.

Na--The Na concentration curves in the procedure C and R H_2O leachates are characteristic of a very soluble parameter. Na concentration in the procedure C H_2O leachate rises and is almost a straight line, reaching over 40,000 mg/l (almost 2M) by the fourth elution. Procedure R curves show a first elution maximum with much lower values thereafter. There is no hint of a concentration plateau in the procedure C leachates, so even after four elutions the maximum concentration cannot be estimated from the procedure C data.

K--K curves are interesting in that they are similar to the Na curves but at much lower concentrations. Whereas the Na concentration in the first elution leachates is about 10,000 mg/l, K concentration is only 5 mg/l.

Cu--Cu leaching curves show the effect pH can have on the release of trace metals. In the first elution, Cu concentration in SL leachates was approximately 3,000 mg/l, while in the H_2O leachates, it was only 0.5 mg/l. Procedure R SL samples continue to extract high concentrations of Cu until all available Cu is extracted, while the distilled water leachates' Cu concentrations remain near the detection limit. After five elutions, SL leachates had extracted over 100 g/kg Cu, while the H_2O leachates extracted only 3 mg/kg. The major reason for the different leaching behavior of the SL and H_2O leachates is explained by a pH versus Cu concentration phase diagram, as shown in Figure 96. Cu solubility increases rapidly with decreasing pH below pH 9. From the diagram, one would expect a Cu concentration in solution at pH 4.5 to be about four orders of magnitude (10,000 times) higher than the concentration at pH 10.4, assuming no complexing agents are present other than hydroxide. Also plotted in Figure 96 are the Cu concentrations found in the test leachates. The points are generally close to the $CuO-Cu^{++}$ lines,

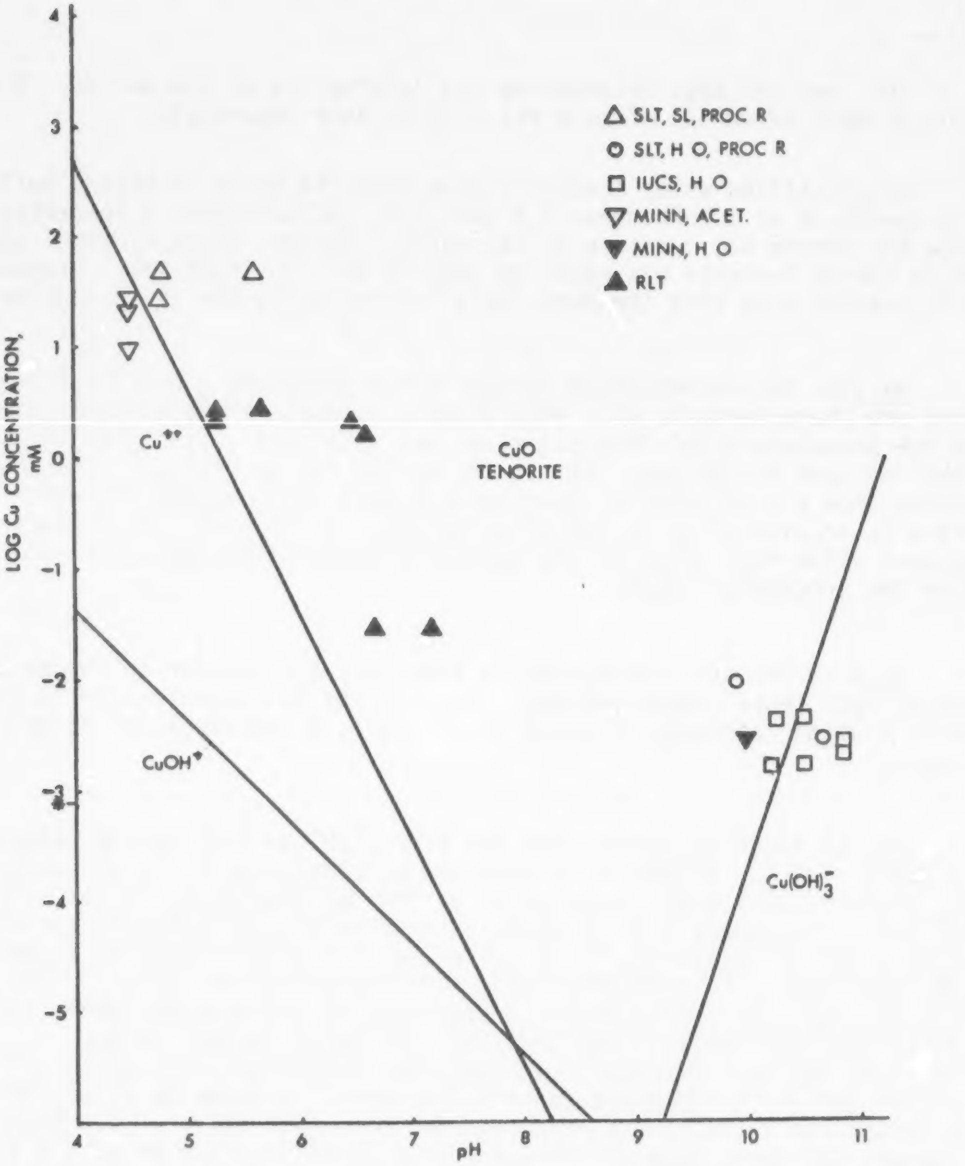

Figure 96. pH vs. Cu concentration solubility diagram for Cu and CuO system.

(Cu concentrations in leachates from CuO-Na_2SO_4 Sludge, using various leaching tests are also plotted.)

*Detection limit using Atomic Absorption spectrometer.

indicating that pH is probably the major controlling factor for Cu concentration. The seemingly oversaturated conditions found in the SL and real leachates samples probably show the effect of complexing in solubilizing Cu.

Falling Cu concentrations in procedure C SL samples indicate that Cu is being lost from solution in each elution after the first. The rising pH of these leachates explains the loss of Cu from solution. Apparently, however, the strong complexing capacity of SL maintains Cu concentrations well above that predicted from pH considerations alone.

Mg--The procedure C SL Mg curve also shows a pH effect, with a fall in Mg concentration as the pH rises. The procedure R SL curve shows almost complete extraction of leachable Mg on the first elution with low concentrations thereafter. Mg concentrations in first elution SL samples in procedures C and R do not duplicate well. Concentrations range from 750 to 2500 mg/l in the three replicates. This range is far beyond usual Mg deviations (~10% standard deviation). Whether the lack of duplication was caused by subsampling differences or by changes in the SL causing changes in the Mg concentration is unknown.

There is an interesting rise in Mg concentration in H_2O leachates in both procedures C and R samples to around 100 mg/l. Why Mg should elute in later elutions and not in the initial elutions is not known.

Summary--The waste is a mixture of basic salts of Cu, Mg, and Na. Cu and Mg are leached in high concentrations by acid media, but not by H_2O leachates. In the acid environment of a municipal landfill, this waste would probably release significant amounts of Cu to the surrounding environment. This release is foreseen in the acid media but is completely missed by the H_2O leachates. The differences in the Cu concentrations are so large that one could not predict the Cu concentrations possible under acid conditions from the H_2O leachates alone. The H_2O leachates, on the other hand, show that the waste will not leach high concentrations of Cu unless subjected to acid or strongly complexing conditions. Both acid and H_2O leachates are needed to obtain a clear picture of the leaching characteristics of the waste.

The high releases from the waste indicate that most of the waste is dissolving in the acid leachates. Assuming that Na is present in the waste as Na_2SO_4 and is leached equally well under H_2O and acid conditions, and that Cu and Mg are present as CuO and $MgSO_4$, respectively, the percentage of waste dissolved can be calculated from the release figures. For SL samples, the calculated percentages are around 100% (98.4% for one duplicate, 105.3% for the other). Whether or not the assumptions regarding the waste composition are correct, it is obvious from the calculations that a large portion of the waste is dissolved in SL.

It would be surprising if large quantities of this waste were actually landfilled. With large amounts of Cu easily extractable from the waste, it is a prime candidate for Cu recovery.

Test Comparison--

The test comparison data show the same general trends as the SLT data discussed previously, namely, high Na release in H_2O leachates and high Mg and Cu releases in acid leachates.

There is an interesting difference between the Na release patterns in the IUCS and SLT procedure R H_2O leachates (Figure 4). Na concentration in the SLT procedure R H_2O leachate drops from an initial high (10,000 mg/l) in the first elution to steady values of around 1000 mg/l in subsequent elutions. The IUCS leachate Na concentrations, on the other hand, fell steadily for four elutions. When transformed into release, these concentrations and the different solid-liquid ratios indicate a release in the first elution of the SLT comparable to the cumulative release attained with the IUCS test after five elutions, both on a grams Na released per kg waste basis. In other words, the SLT leached in one day more than the IUCS test leached in 10 days. Further, the SLT continued to leach more Na in three of the four elutions performed beyond the first; whereas the IUCS leached very little additional Na in the third, fourth, or fifth elutions. The test results indicate that the Na is present as a very soluble and rapidly leached salt (probably Na_2SO_4, given the name of the waste). One possible explanation of the slower release of Na in the IUCS test is that the agitation procedure in the IUCS test does not mix the waste and leachate as thoroughly as the agitation procedure in the SLT, thus delaying release of the Na. In the IUCS test, the waste lies on the bottom of the flask while the leachate is sloshed back and forth on top of the waste. The SLT agitation procedure gently tumbles the waste as the flask is turned through a verticle circle. Anyone who has tried to dissolve a large amount of salt in a volumetric flask can attest to the fact that just swirling the flask is not as effective at dissolving the salt as tilting it back and forth. The same situation may be present here.

Cu concentrations in the RLT demonstrated that municipal landfill leachate was able to solubilize significant amounts of Cu. The concentrations in the RLT leachates were not as high as those in the acid leachates, but the pH of the RLT leachates was higher than that in the acid leachates. The very large difference in Cu concentrations between acid and H_2O leachates observed in the SLT was also seen in the other test leachates. The acetate buffer contained very high concentrations of Cu (~1500 mg/l), while H_2O leachates were less than 0.5 mg/l.

TABLE 29. ELECTROPLATING SLUDGE (EPS):
DESCRIPTION AND SUMMARY OF RESULTS

Waste Number 12, Obtained Locally

Description:

Two jars of the sludge were obtained. One had red spots on the outside, the other was black. Both had very little free liquid. Sludge was not homogeneous, but rather had pockets of a clay-like material distributed throughout.

Analysis:

pH (of free liquid) 8.40; 72% volatile at 105°C for 24 hours.

Sample Preparation:

Liquid removed by filtration through a Whattman 42 filter, then through a 0.45 micron filter. Sample homogenized by gentle grinding with mortar and pestle.

(continued)

TABLE 29 (continued)

Maximum Concentration and Release

	Na	K	Mg	Zn	Cd
Concentration, mg/l					
Acid leachates					
SLT proc. C, SL		69.9	532	45	7.50
SLT proc. R, SL		42.3	343	160	19.9
Minn.		21.5	125	210	7.4
H_2O leachates					
SLT proc. C	167	43.3	190	0	0
SLT proc. R	79	16.6	83.4	0	0
IUCS	92	22	28	0	0
Minn.	29.8	6.3	8.3	0	0
Release mg/kg					
Acid leachates					
SLT proc. R, SL		914	6542	6570	943
Minn.		1014	5400	9540	344
H_2O leachates					
SLT proc. R	1081	251	1428	0	0
IUCS	593	160	346	0	0
Minn.	1420	336	508	0	0

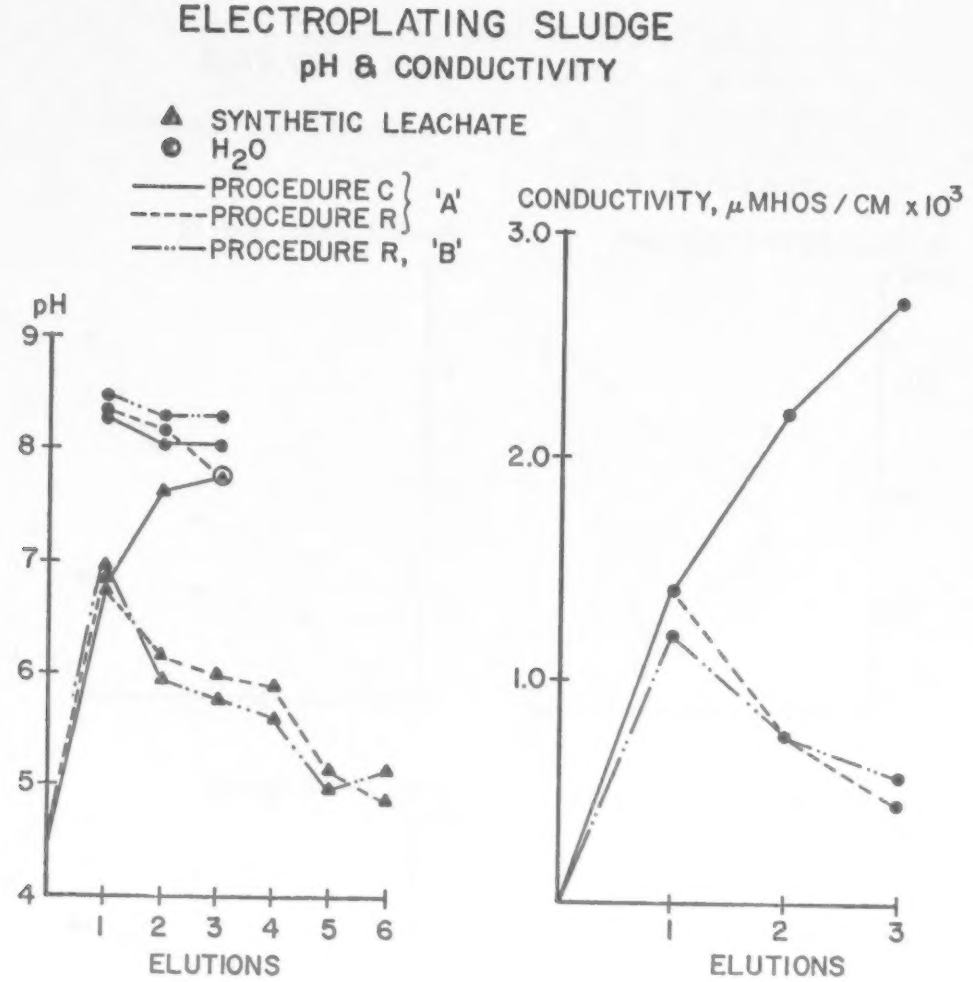

Figure 97. pH and specific conductance curves for Electroplating Sludge, SLT.

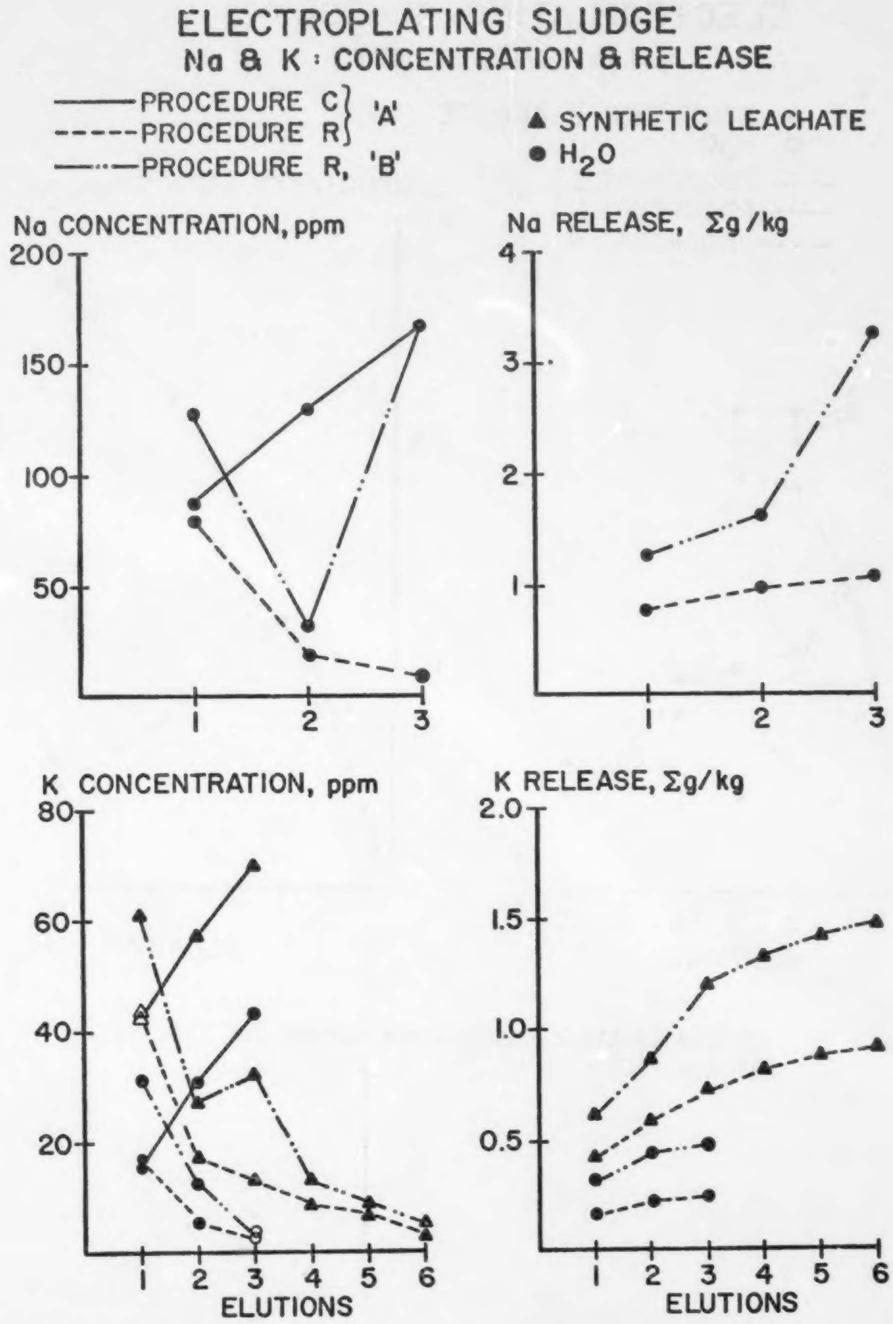

Figure 98. Na and K concentration and release curves for Electroplating Sludge, SLT.

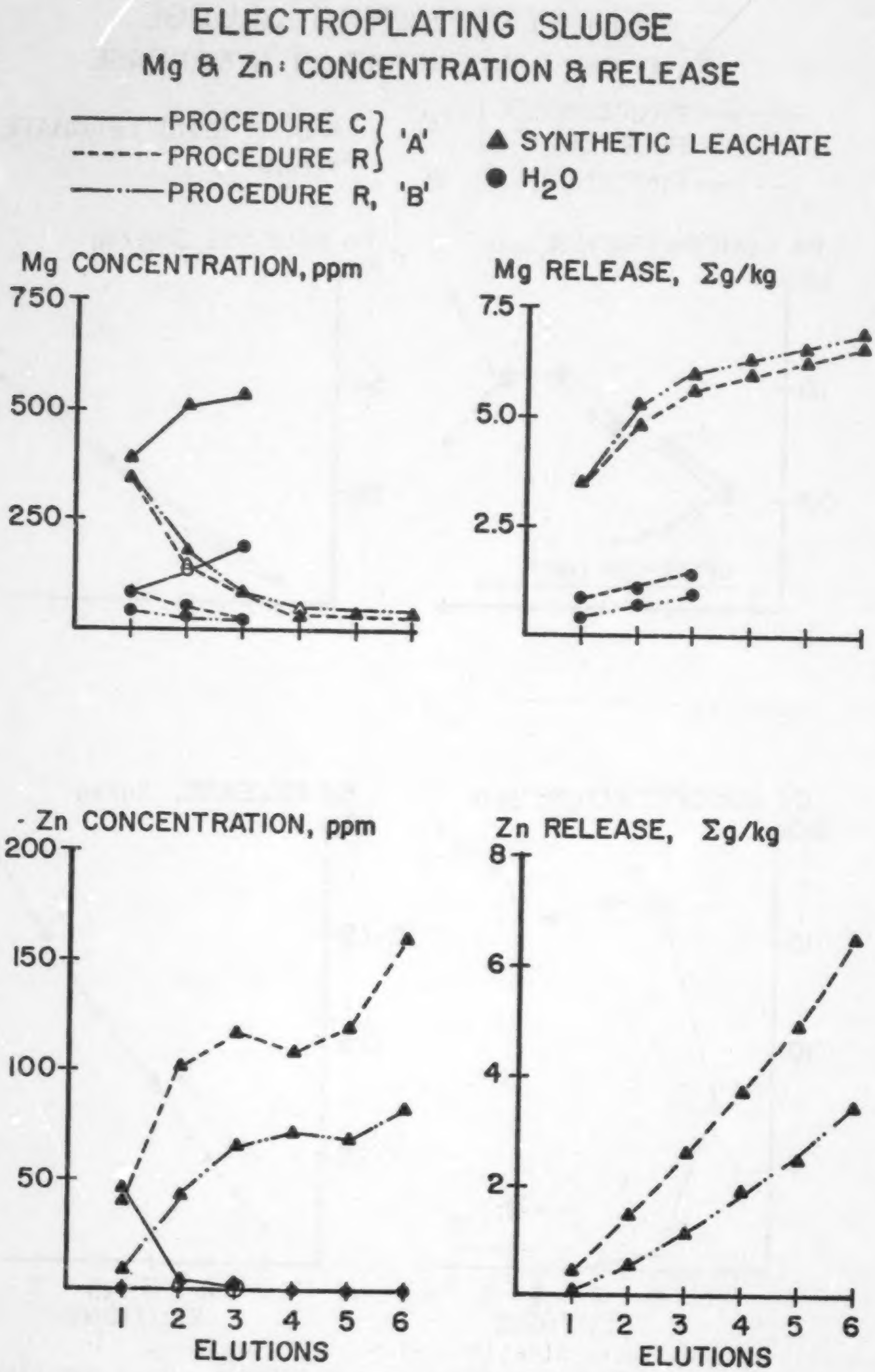

Figure 99. Mg and Zn concentration and release curves for Electroplating Sludge, SLT.

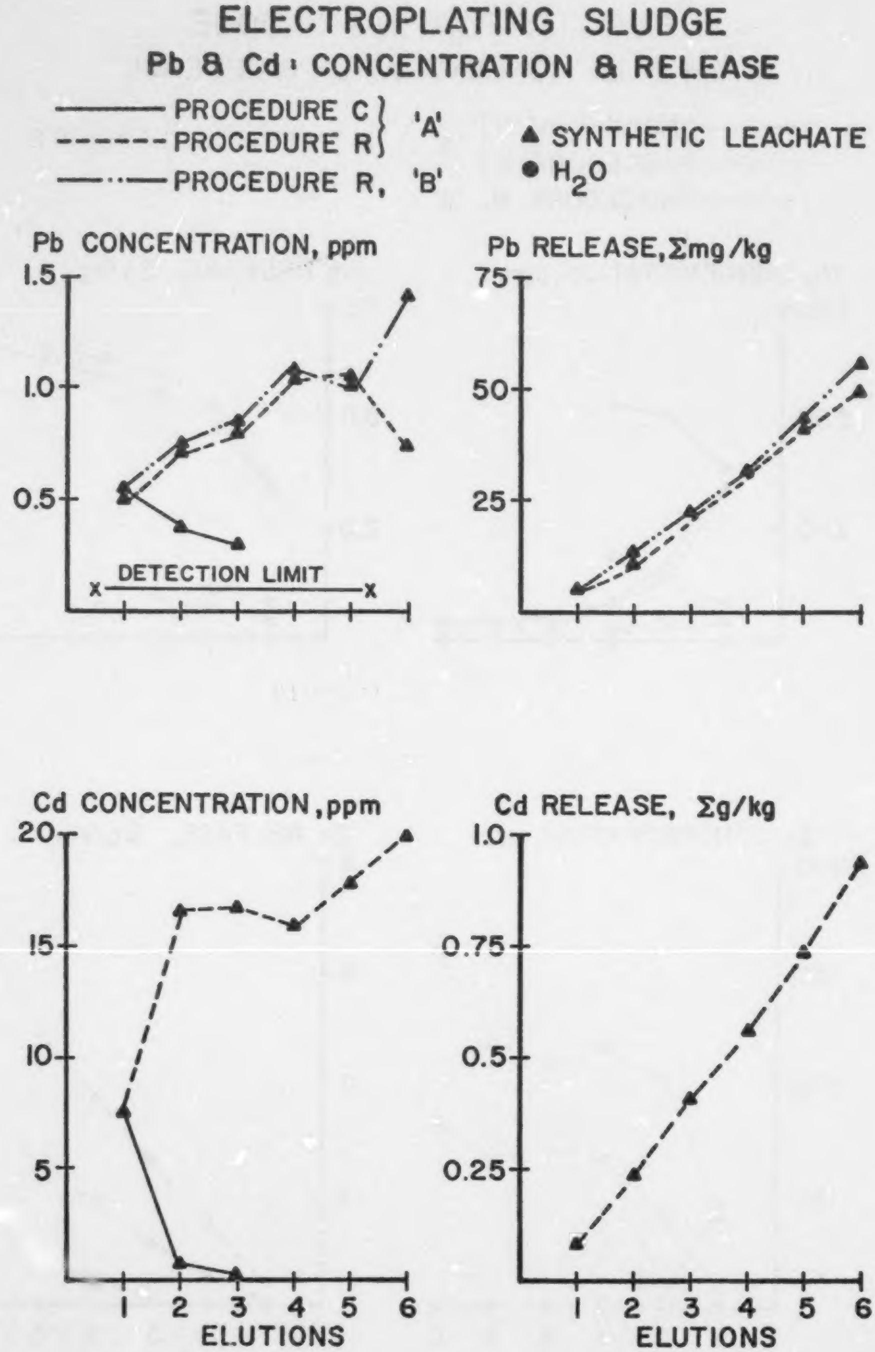

Figure 100. Pb and Cd concentration and release curves for Electroplating Sludge, SLT.

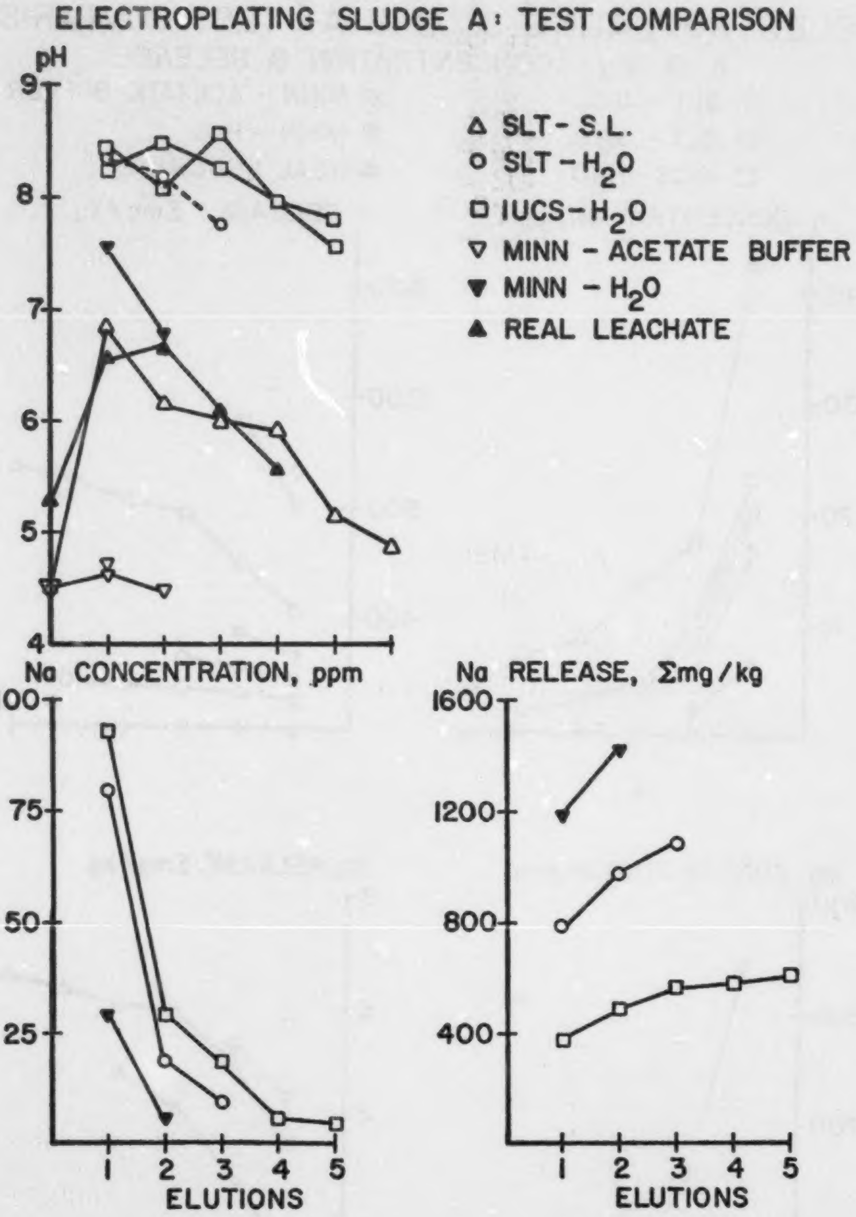

Figure 101. pH and Na concentration and release curves for Electroplating Sludge, test comparison.

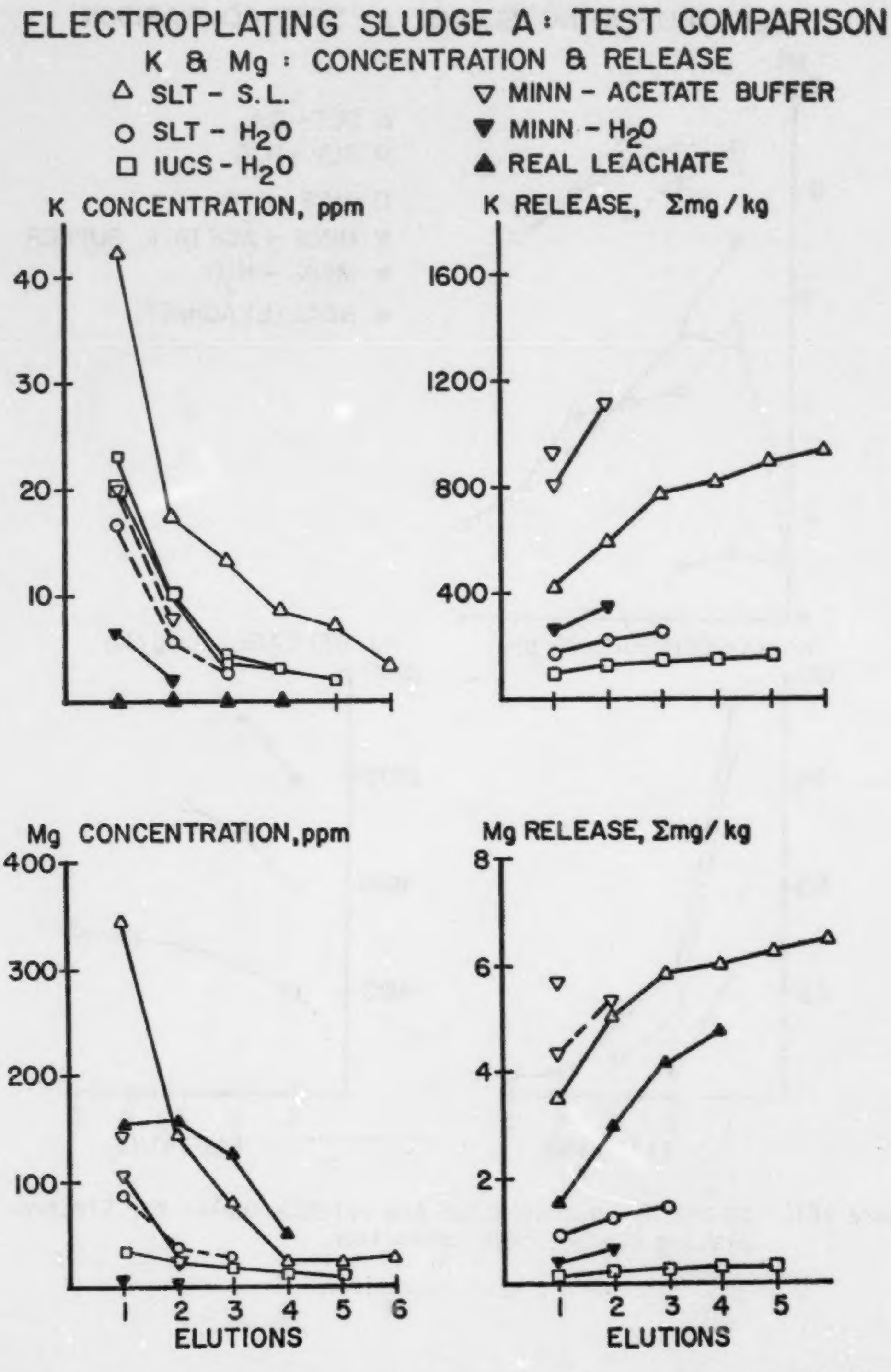

Figure 102. K and Mg concentration and release curves for Electroplating Sludge, test comparison.

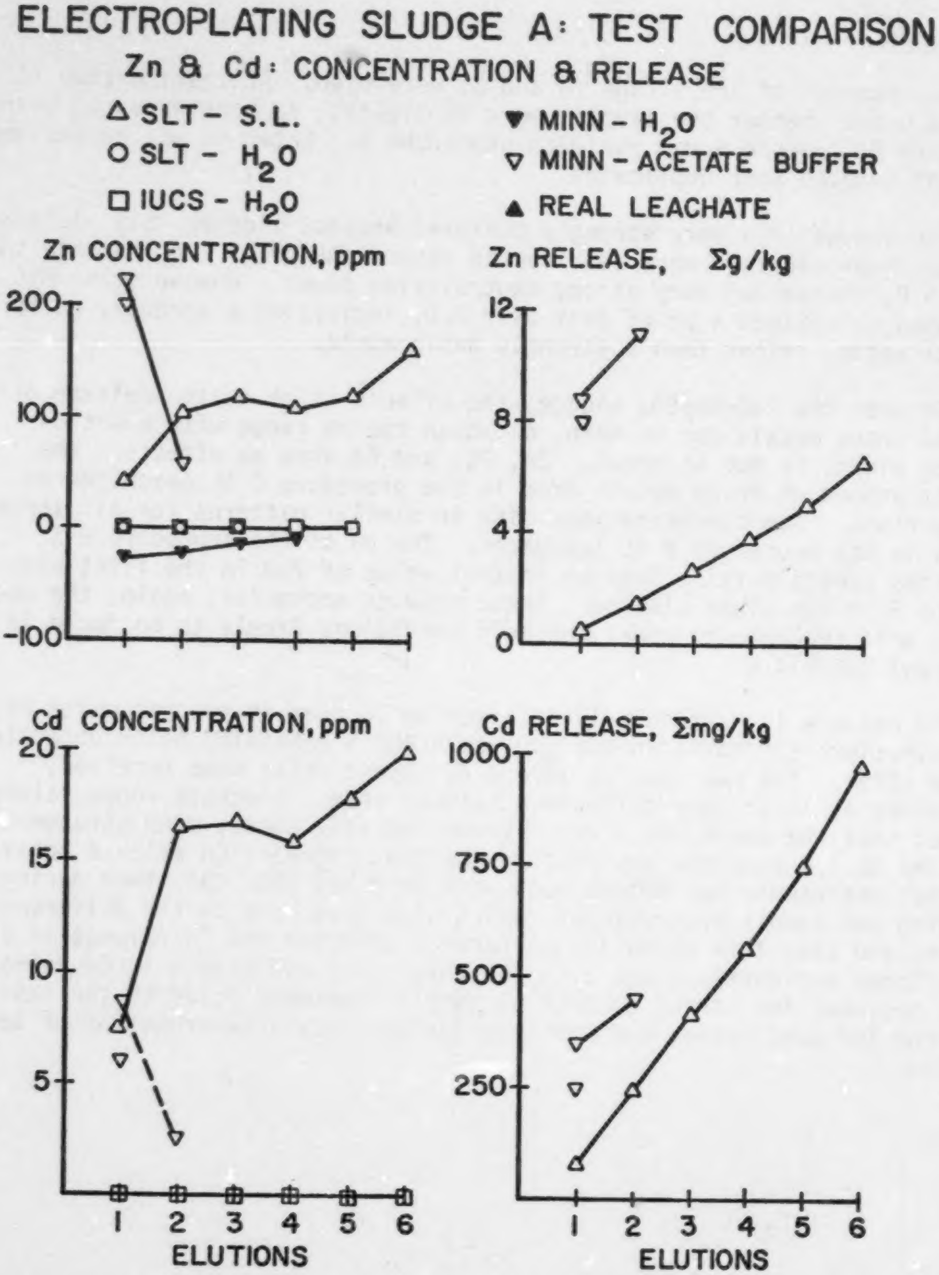

Figure 103. Zn and Cd concentration and release curves for Electroplating Sludge, test comparison.

Discussion

Two samples of the sludge (A and B) were used. At testing time it was not known whether the samples were duplicates, so both were run using procedure R. Sample A was run with procedure C. Later it was determined that the samples were duplicates.

The sludge is a very strongly buffered neutral sludge. Six elutions with SL in procedure R were required to return the pH of the leachate to below 5.0, indicating very strong neutralizing power. However, the H_2O leachates maintained a pH of just over 8.0, indicating a strongly buffered neutral waste, rather than a strongly basic waste.

As with the $CuO-Na_2SO_4$ sludge, the effects of pH on the release of several trace metals can be seen, although the pH range with electroplating sludge is not as great. Zn, Pb, and Cd show pH effects. The concentrations of these metals drop in the procedure C SL leachates as the pH rises. The concentrations rise in similar patterns for all three metals in the procedure R SL leachates. The pH of the procedure R SL leachates steadily falls from an initial value of 7.0 in the first elution to 5 in the sixth elution. These results emphasize, again, the need for an acid leachate to model the acid conditions likely to be found in municipal landfills.

Cd release is particularly interesting in that it reaches quite high concentrations (20 mg/l) in one duplicate while remaining below detection in the other. The two samples were a different color when received, indicating at least some difference between them. Leachate redox values showed that the waste was a very strong reducing agent, much stronger than the SL. A possible explanation for the different Cd release behavior was that one sample had become much more oxidized than the other during shipping and sample pretreatment, which also gave rise to the different colors, and that this oxidation difference affected the Cd release in some way. Other explanations are also possible. The difference in Cd release shows the need for strict control of sample treatment prior to the test, the need for duplicates, and the need for cautious interpretation of test results.

TABLE 30. WASTEWATER TREATMENT SLUDGE (WTS):
DESCRIPTION AND SUMMARY OF RESULTS

Waste Number 13, Chem-Trol

Description:

A suspension from a typical industrial wastewater treatment plant employing coagulation/precipitation and lime softening. It will consist of various heavy metals and other metals precipitated as hydroxides, chelated, chemisorbed, or otherwise "fixed" in the sludge.

Analysis:

CHEM-TROL: Fe 11%, Cu 2.9%, Cr 0.6%, Zn 1.3% (% of dry weight), pH 11.0, sp. gr. 3.4, approximately 80% water, high viscosity.

Wisconsin: pH of liquid 12.57, redox -45 mV vs S.C.E.

Solids: 51.2% volatile at 105°C for 24 hours
79% volatile at 600°C

Sample Preparation:

Liquid decanted, filtered, solids from filtered liquid returned to settled solids and mixed. Solids then refiltered.

TABLE 30 (continued)

Maximum Concentration and Release

Concentration, mg/l

Acid leachates	Na	K	Mg	Zn	Cu
SLT procedure C, SL		190	1.4	2.0	156
SLT procedure R, SL		40	250	18.5	292
Minn.		15	78	9.2	69
Real leachate	480		loss from solution	loss from solution	30
H_2O leachates					
SLT procedure C	3200	146	0	1.0	6.8
SLT procedure R	1425	29	0	0.9	3.5
Minn.	95	4	0	0	0.2

Release, mg/kg

Acid leachates	Na	K	Mg	Zn	Cu
SLT procedure R, SL		923	5670	464	5820
Minn.		600	3120	368	2760
Real leachate	5000		loss from solution	loss from solution	640
H_2O leachates					
SLT procedure R	26100	334	0	23	55
Minn.	3800	160	0	0	8

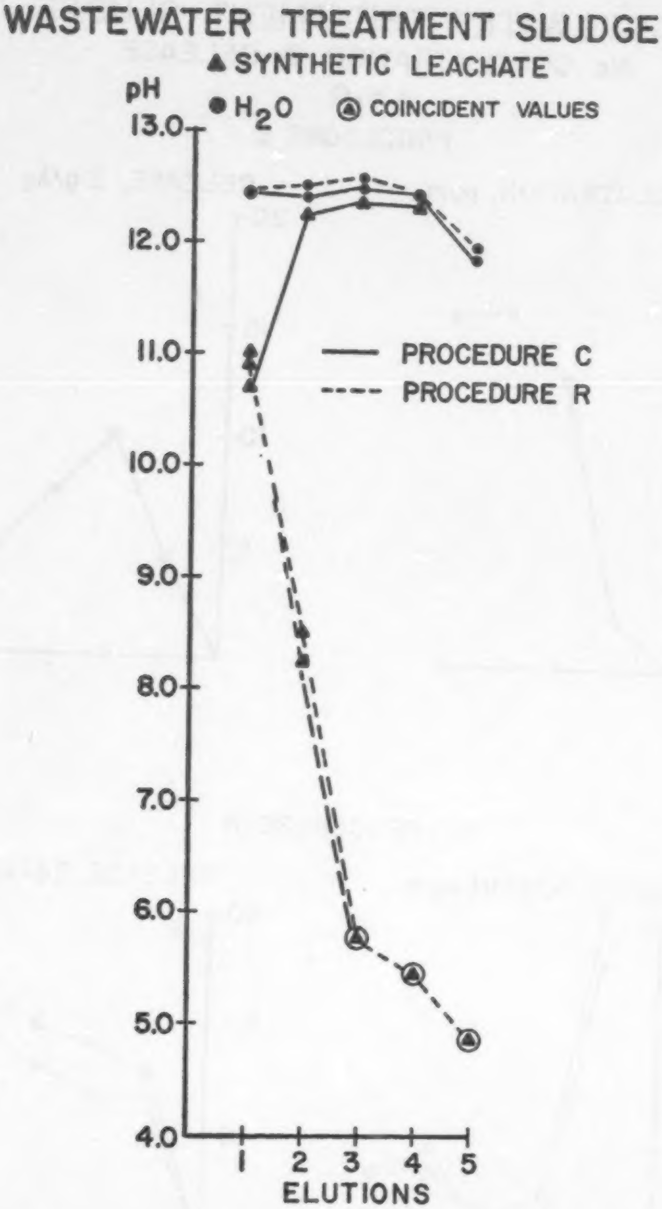

Figure 104. pH curve for Wastewater Treatment Sludge, SLT.

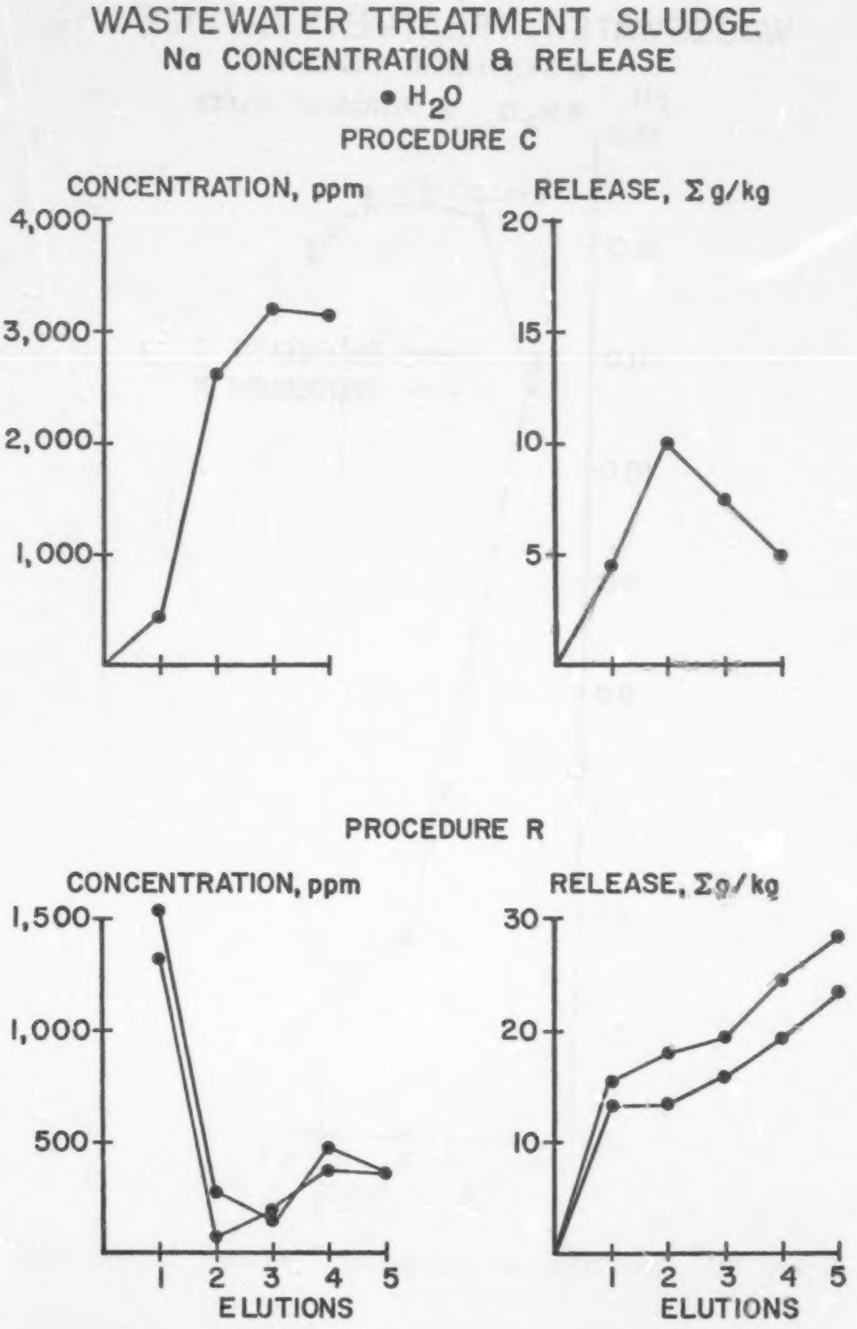

Figure 105. Na concentration and release curves for Wastewater Treatment Sludge, SLT.

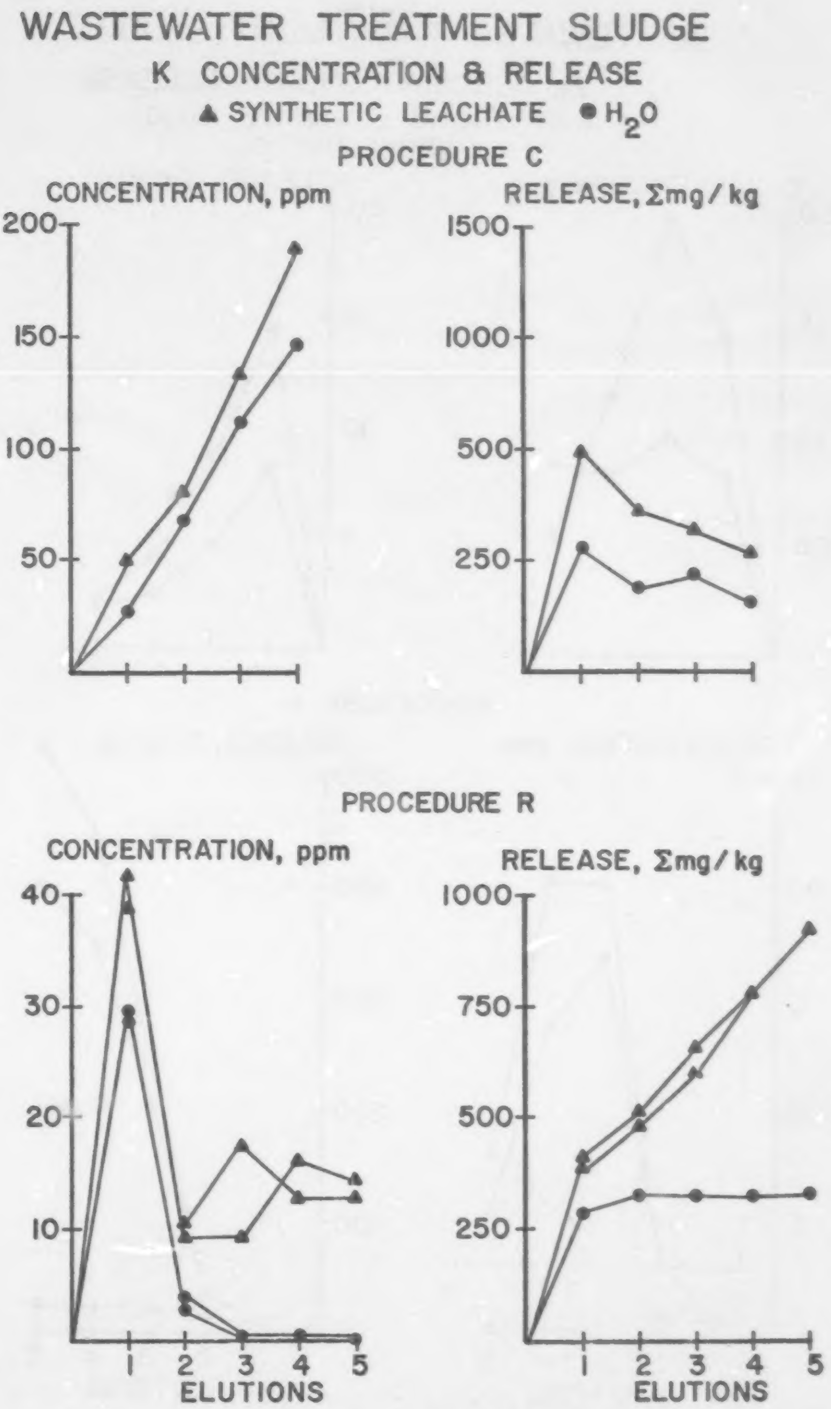

Figure 106. K concentration and release curves for Wastewater Treatment Sludge, SLT.

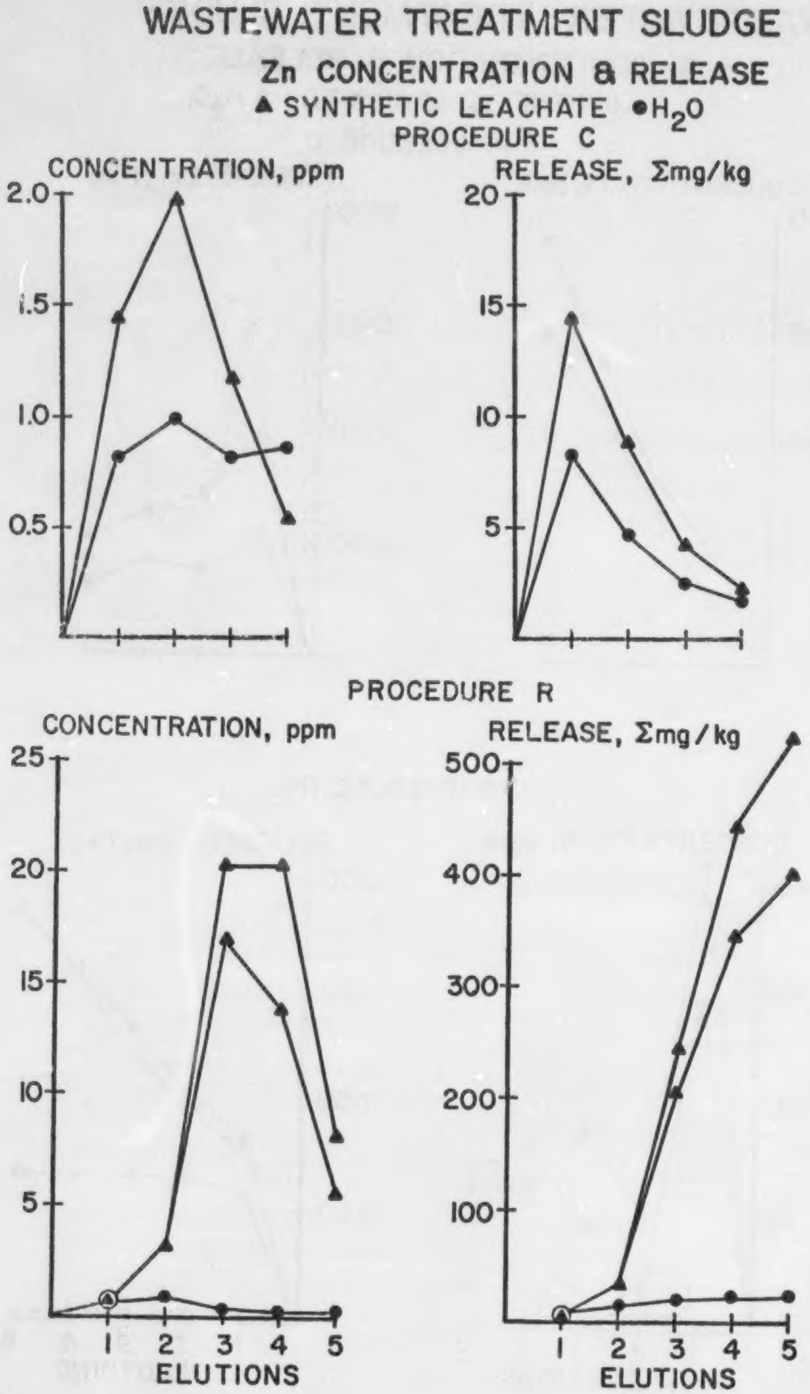

Figure 107. Zn concentration and release curves for Wastewater Treatment Sludge, SLT.

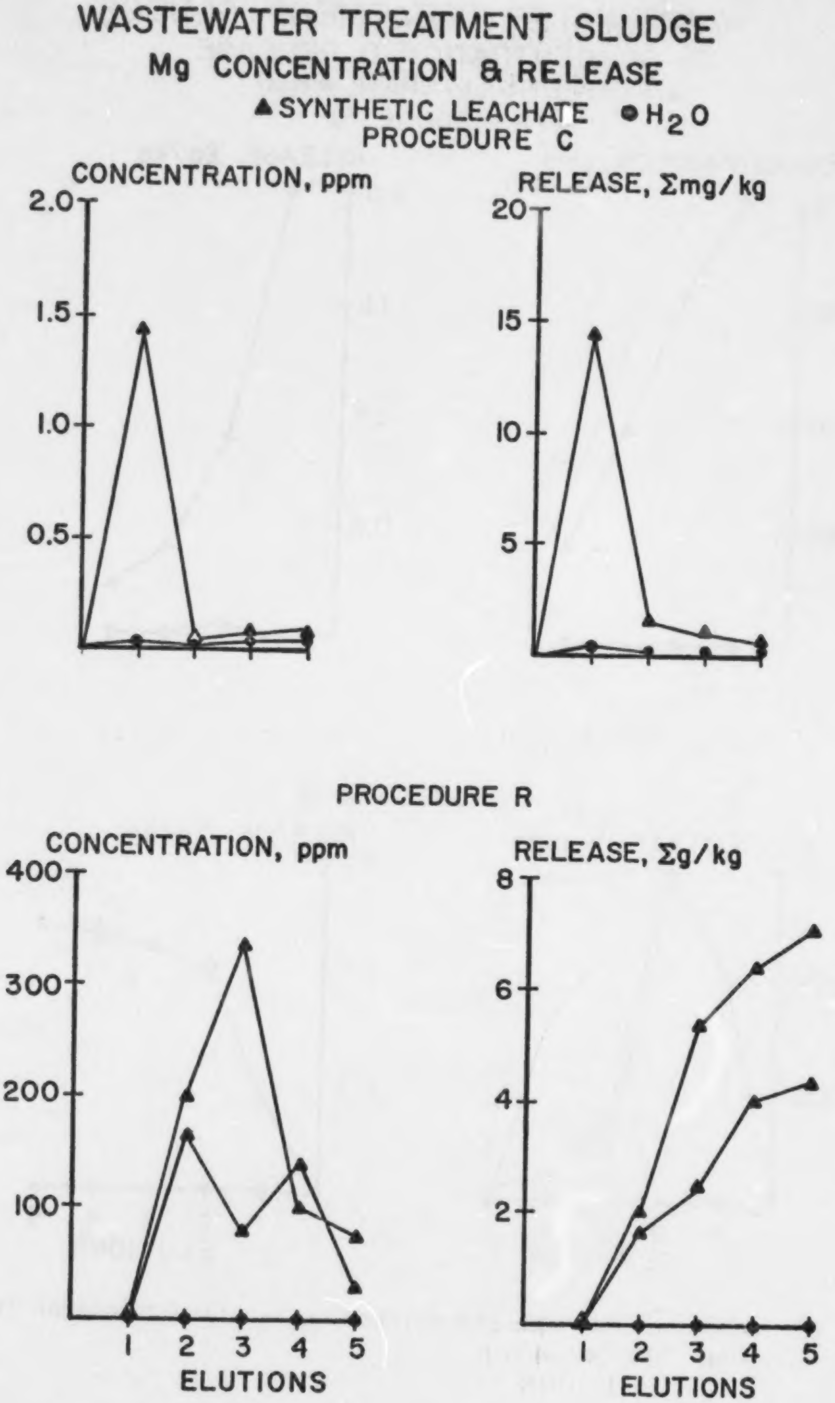

Figure 108. Mg concentration and release curves for Wastewater Treatment Sludge, SLT.

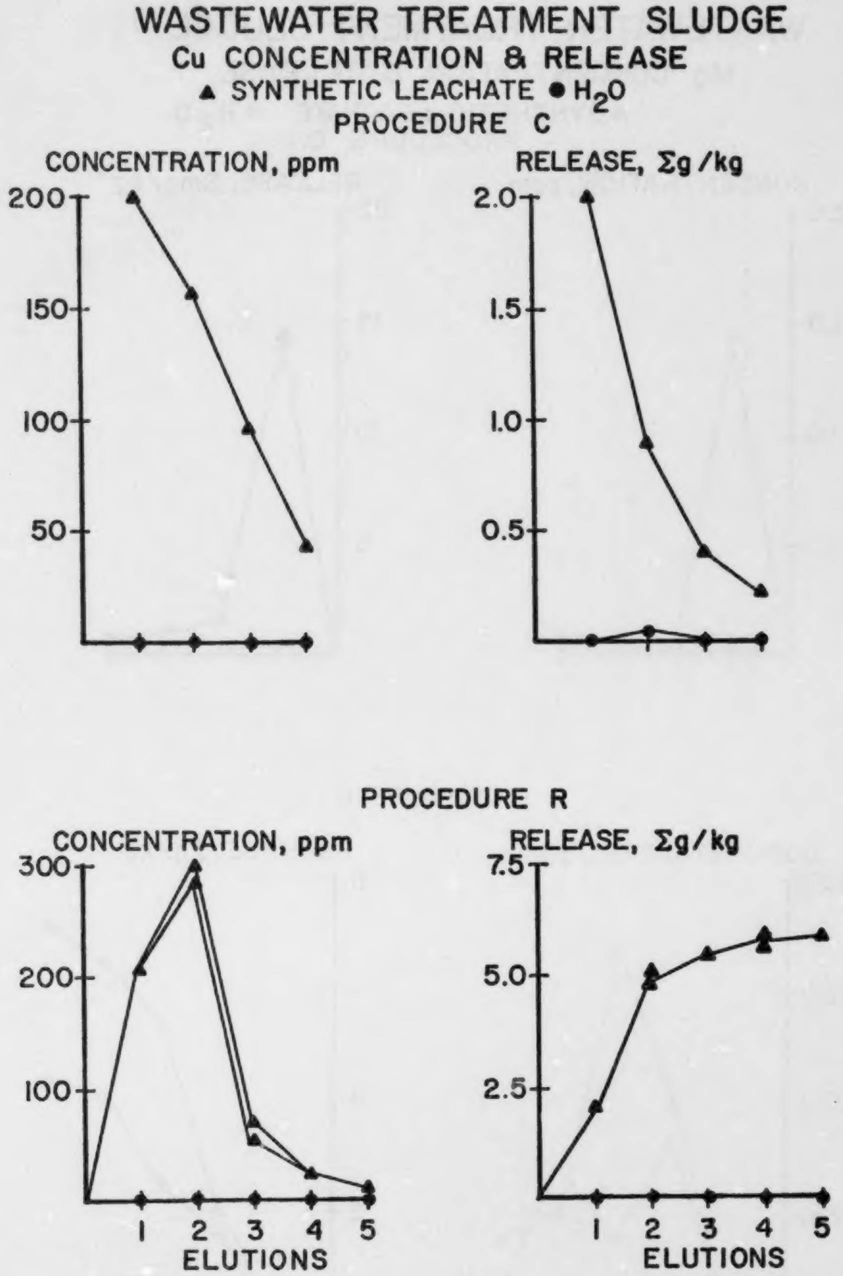

Figure 109. Cu concentration and release curves for Wastewater Treatment Sludge, SLT.

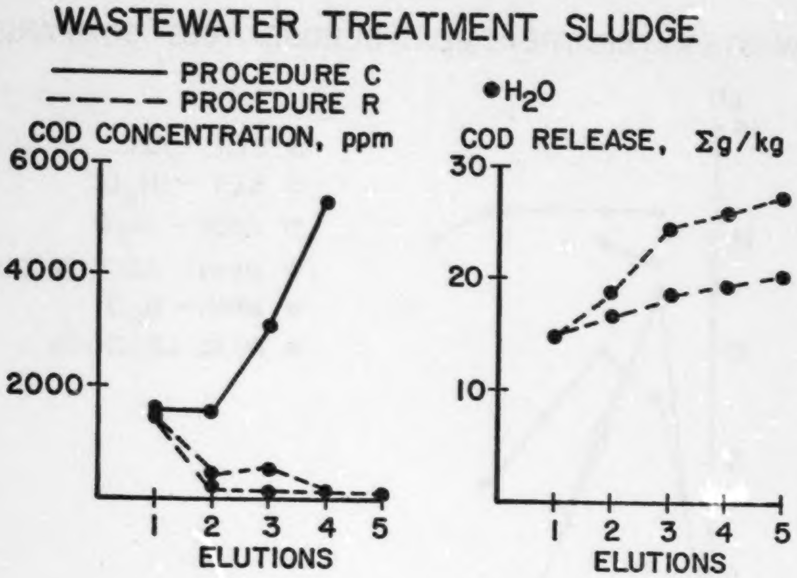

Figure 110. COD concentration and release curves for Wastewater Treatment Sludge, SLT.

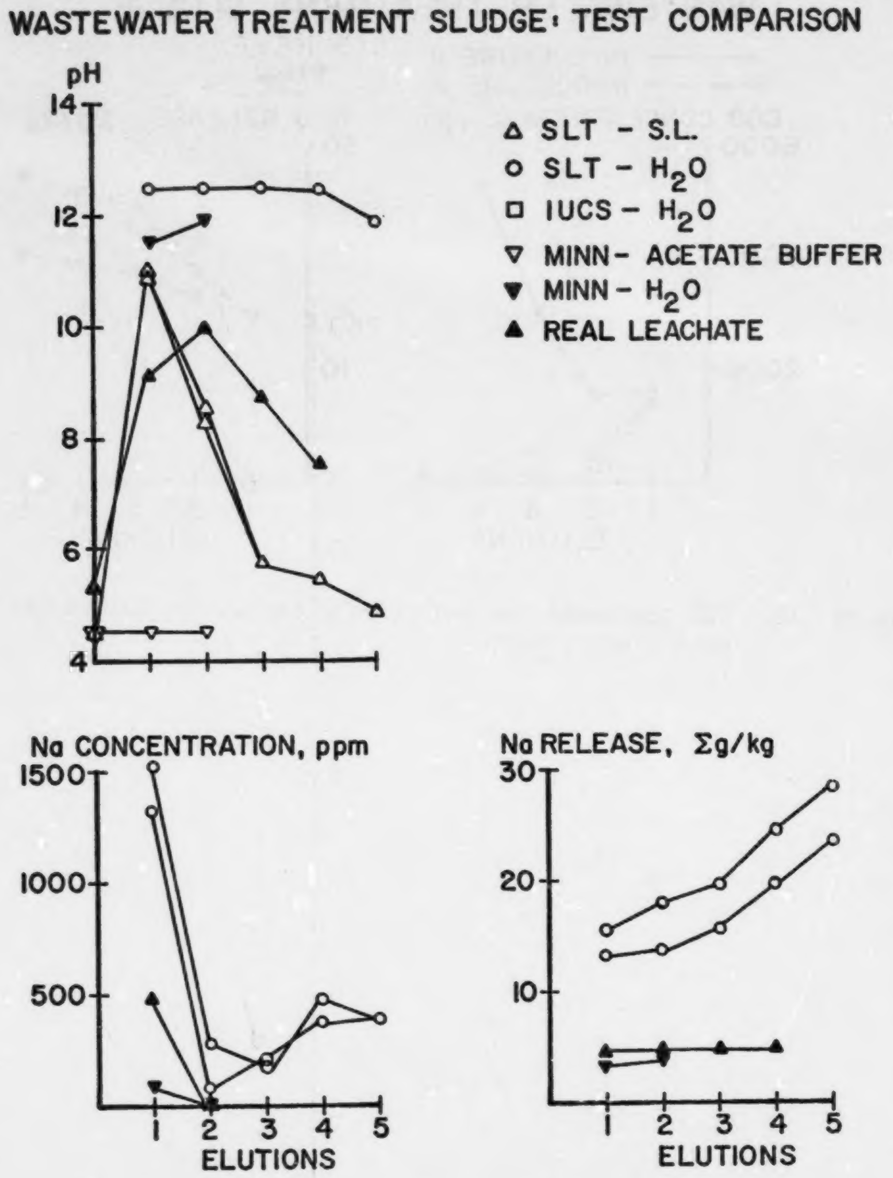

Figure 111. pH and Na concentration and release curves for Wastewater Treatment Sludge, test comparison.

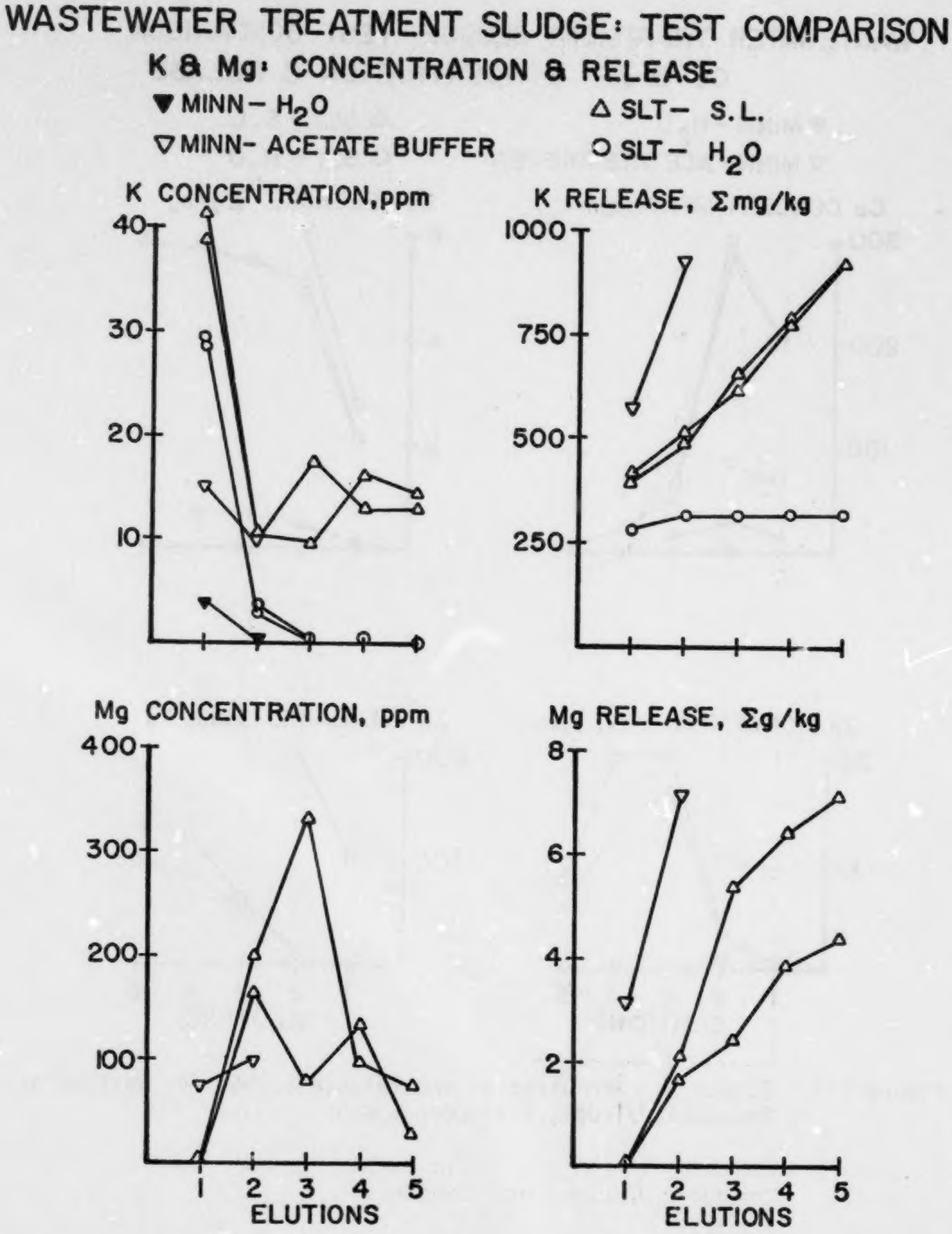

Figure 112. K and Mg concentration and release curves for Wastewater Treatment Sludge, test comparison.

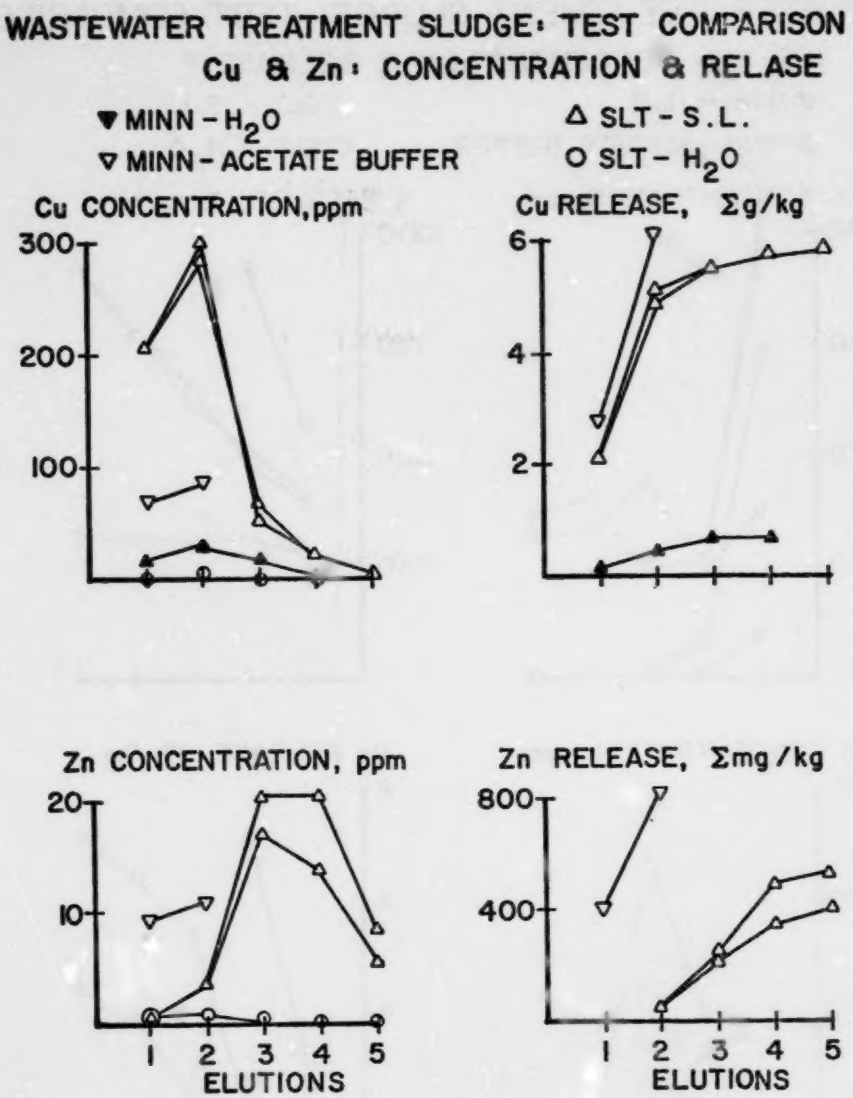

Figure 113. Cu and Zn concentration and release curves for Wastewater Treatment Sludge, test comparison.

Discussion

Wastewater treatment sludge is a strongly basic waste, raising the pH of the first SL elution to around 11. The pH of subsequent procedure R SL leachates fell until reaching below 5.0 in the fifth elution. The H_2O leachates maintain pH values of 12.0 to 12.5. Cu, Mg, and Zn have particularly interesting release curves, primarily due to the apparent effect of pH on their solubility. The Cu concentration in procedure C SL leachates reaches a maximum (200 mg/l) in the first elution and falls steadily thereafter. The pH of the second through fourth and last elution leachates is relatively constant, so the observed drop in Cu concentration during these elutions must be due to removal of Cu by the fresh waste, rather than simply precipitation due to the high pH. Since the Cu concentrations are well above those expected on the basis of pH considerations (see Figure 96), it is apparent that complexing is instrumental in maintaining the high Cu concentrations. Adding fresh waste may either decrease the complexer concentration in solution, replace the Cu in the complex with another metal, or add a species to the system which can extract the Cu from the complex and precipitate it. Procedure R SL leachates have a Cu maximum in the second elution, with falling concentrations thereafter. Possibly during the first two elutions the Cu concentration is controlled by pH, while after the second elution most of the extractable Cu has been leached. Note that as with both $CuO - Na_2SO_4$ sludge and electroplating sludge, the Cu concentrations in the H_2O leachates are very low and give no indication of the Cu leaching potential under acid conditions.

Test Comparison --

Minn., SLT, and RLT tests were run on the waste. Cu concentrations in the RLT leachates are lower than those in the acid leachates, but are much higher than those in the H_2O leachates. The same pattern was found in the $CuO-Na_2SO_4$ tests, and the same comments apply.

pH values in the Minn. acetate buffer leachates showed that the greater buffering capacity of the acetate buffer compared to SL and the lower solid to liquid ratio in the Minn. test compared with the SLT compensate for the strongly basic nature of the waste.

TABLE 31. PAPERMILL SLUDGE (PMS-EPA):
DESCRIPTION AND SUMMARY OF RESULTS

Waste Number 14, CHEM-TROL

Description:

31% clay slurry with the following characteristics: bi-layered liquid, 20% top layer, cloudy while low-viscosity aqueous suspension; 80% bottom layer, opaque, off-white sludge.

Analysis:

CHEM-TROL: pH 7-8, sp. gr. 1.28;
solids—total carbon 45 ppm, total inorganic carbon 15 ppm

Sample Preparation:

Mixture stirred to obtain a uniform suspension. A subsample was centrifuged to obtain solids.

TABLE 31 (continued)

Maximum Concentration and Release

	Concentration, mg/l					
Acid leachates	Na	K	Mg	Fe	Zn	Cu
SLT procedure C, SL		12	73		2.43	2.65
SLT procedure R, SL		5.3	58		0.6	0.85
H_2O leachates						
SLT procedure C	430	1.5	0.25	0.6	0	0
SLT procedure R	450	0.9	0.2	0.5	0	0

	Release, mg/kg					
Acid leachate	Na	K	Mg	Fe	Zn	Cu
SLT procedure R		121	1225		18.3	15
H_2O leachate						
SLT procedure R	13850	23	8	13.6	0	0

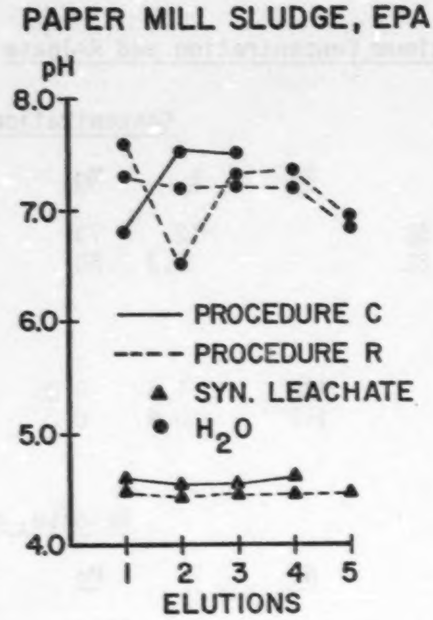

Figure 114. pH curve for Papermill Sludge, EPA, SLT.

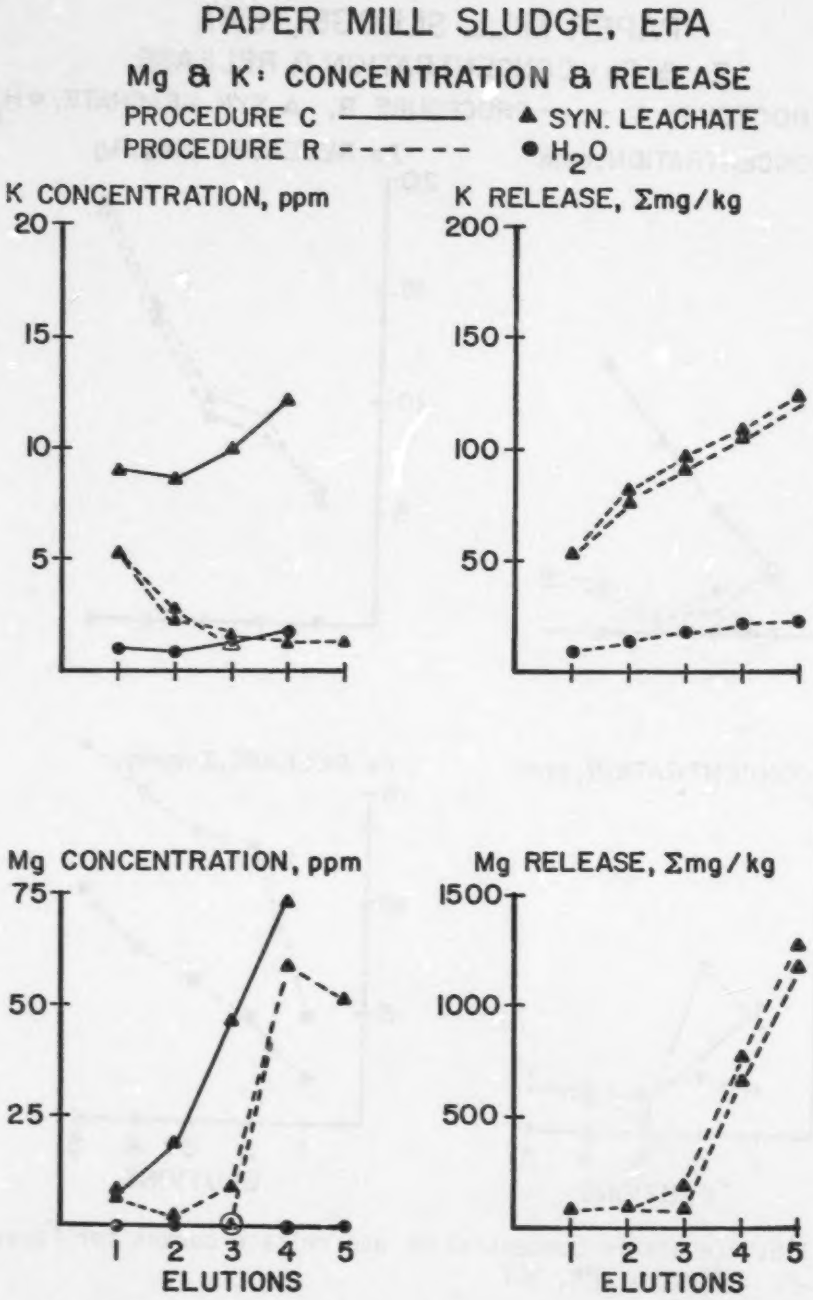

Figure 115. K and Mg concentration and release curves for Papermill Sludge, EPA, SLT.

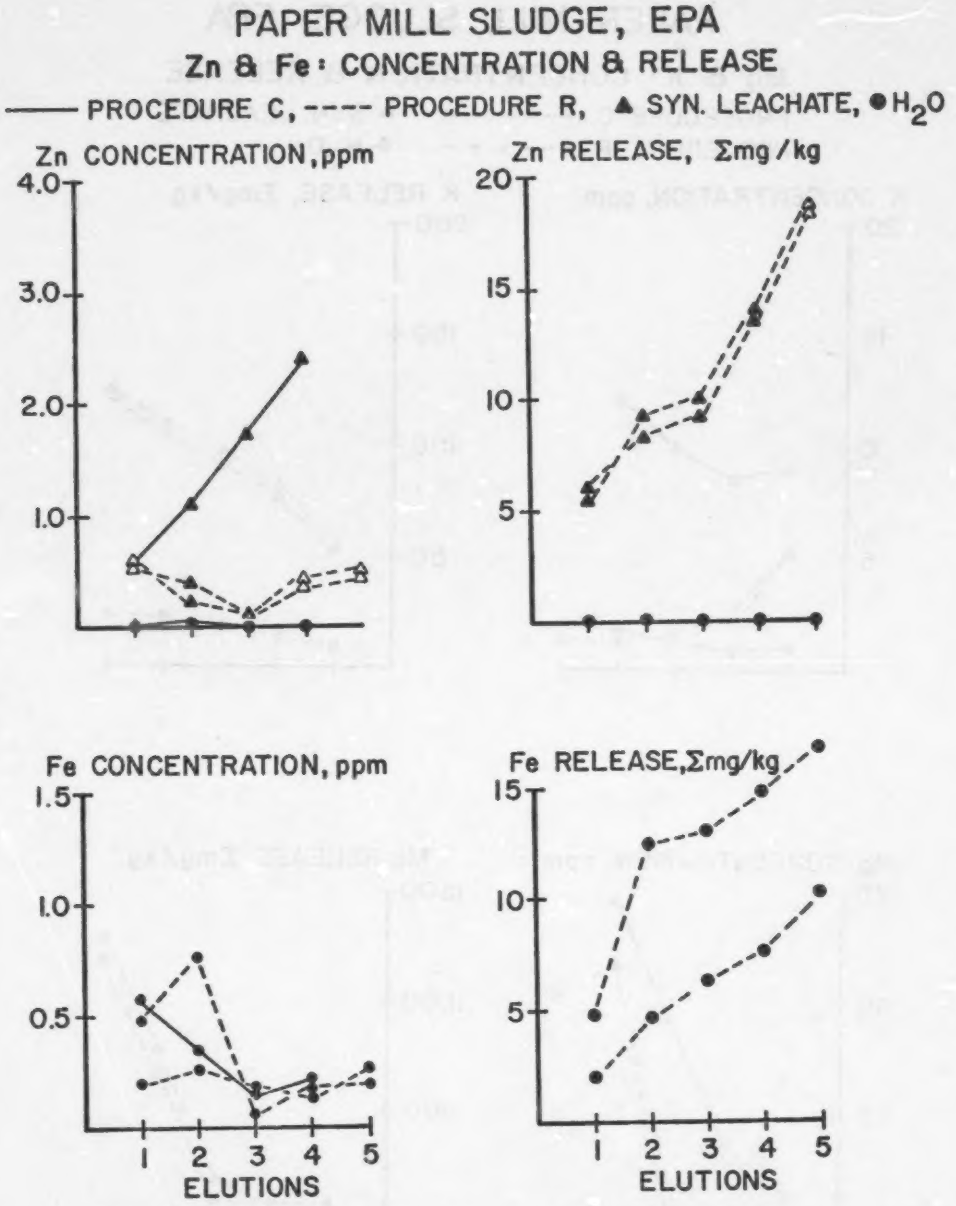

Figure 116. Zn and Fe concentration and release curves for Papermill Sludge, EPA, SLT.

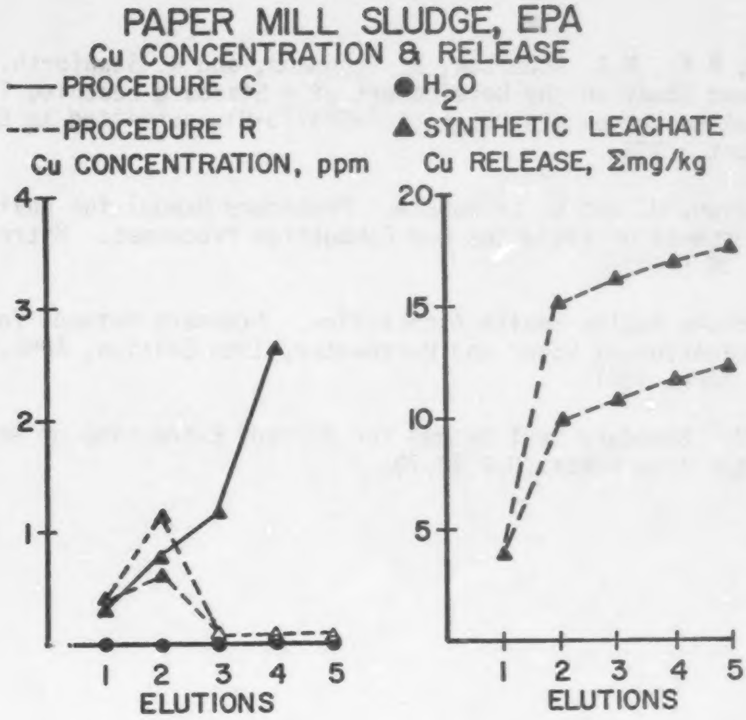

Figure 117. Cu concentration and release curves for Papermill Sludge, EPA, SLT.

REFERENCES

1. Ham, R.K., M.A. Anderson, R. Stegmann, and R. Stanforth. Background Study on the Development of a Standard Leaching Test. Final Report on EPA Contract R-804773-01, submitted to EPA August, 1978.

2. Abelson, H. and W. Lowenbach. Procedure Manual for Environmental Assessment of Fluidized Bed Combustion Processes. Mitre Corp., M77-34 (1977).

3. American Public Health Association. Standard Methods for the Examination of Water and Wastewater, 13th Edition, APHA, Inc., New York, 1971.

4. ASTM. Standard Test Method for Solvent Extraction of Organic Matter from Water, D-2778-70.

APPENDIX

MASS SPECTRA OF COMPOUNDS IDENTIFIED IN WASTE HEXANE EXTRACTS

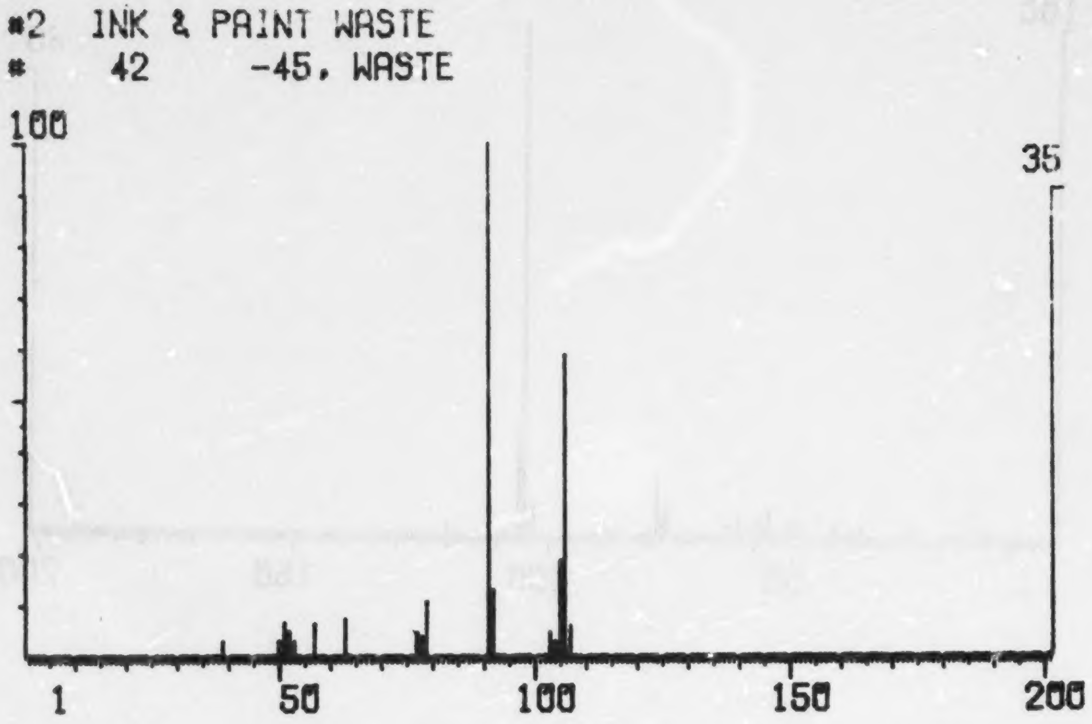

Figure A-1. Mass spectrum of xylene identified in Ink and Paint Waste hexane extract.

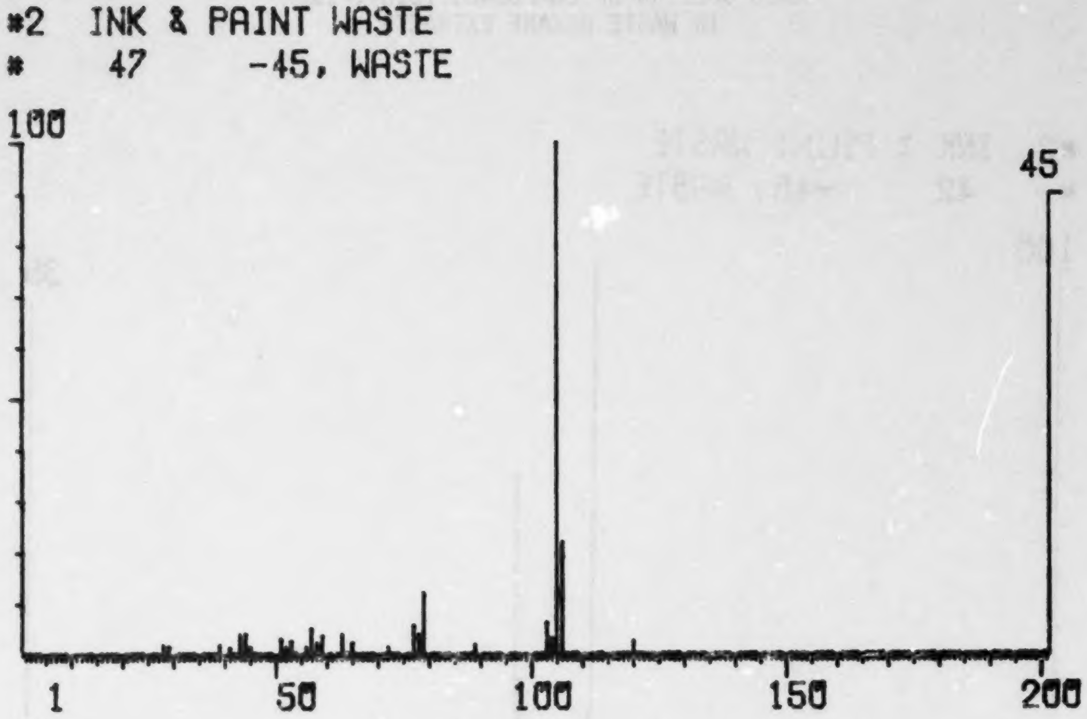

Figure A-2. Mass spectrum of cumene identified in Ink and Paint Waste hexane extract.

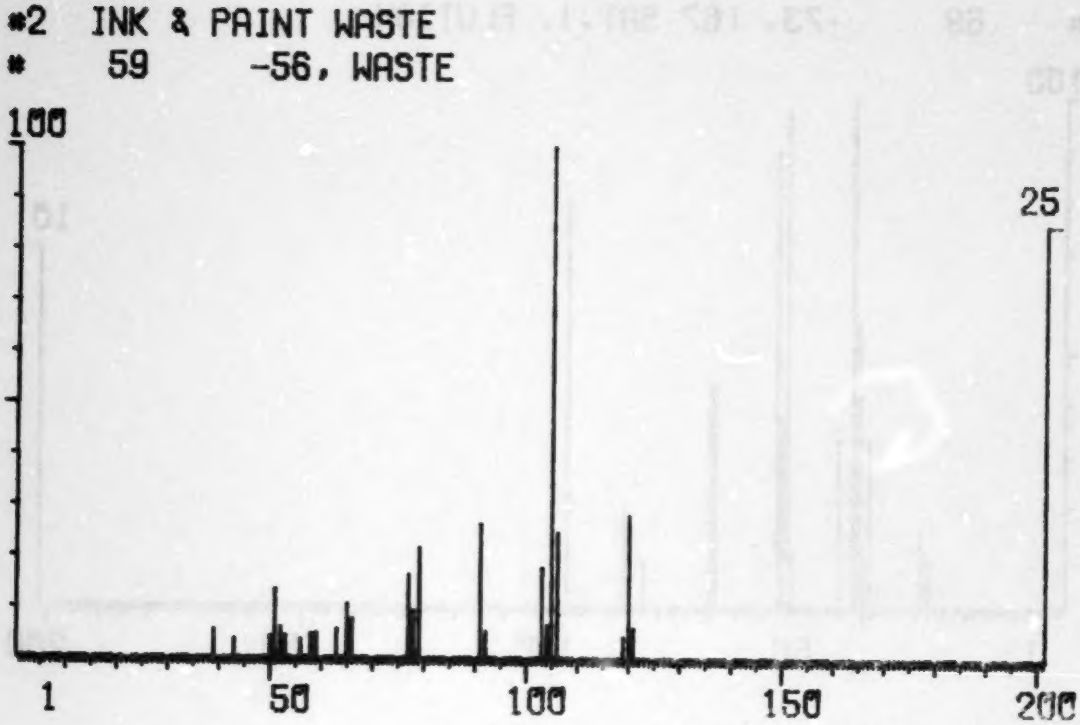

Figure A-3. Mass spectrum of m-ethyltoluene identified in Ink and Paint Waste hexane extract.

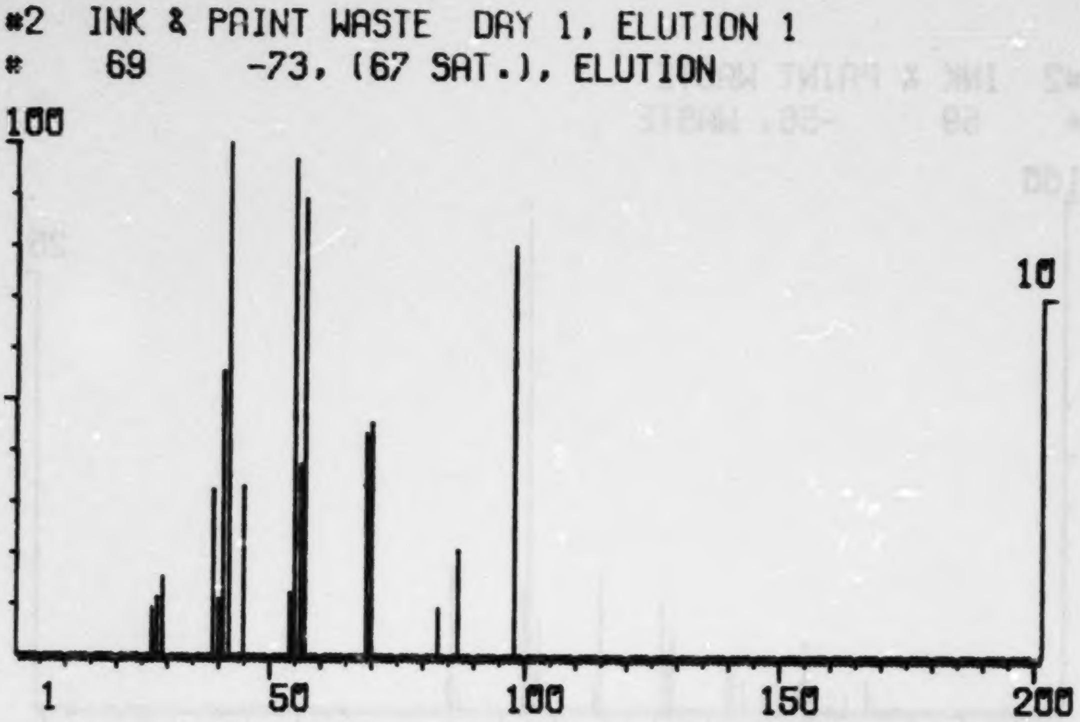

Figure A-4. Mass spectrum of cyclohexanone identified in Ink and Paint Waste hexane extract.

(Spectrum in hexane extract was too close to background for a clear spectrum, so corresponding spectrum from SLT H_2O leachate, day 1, is presented.)

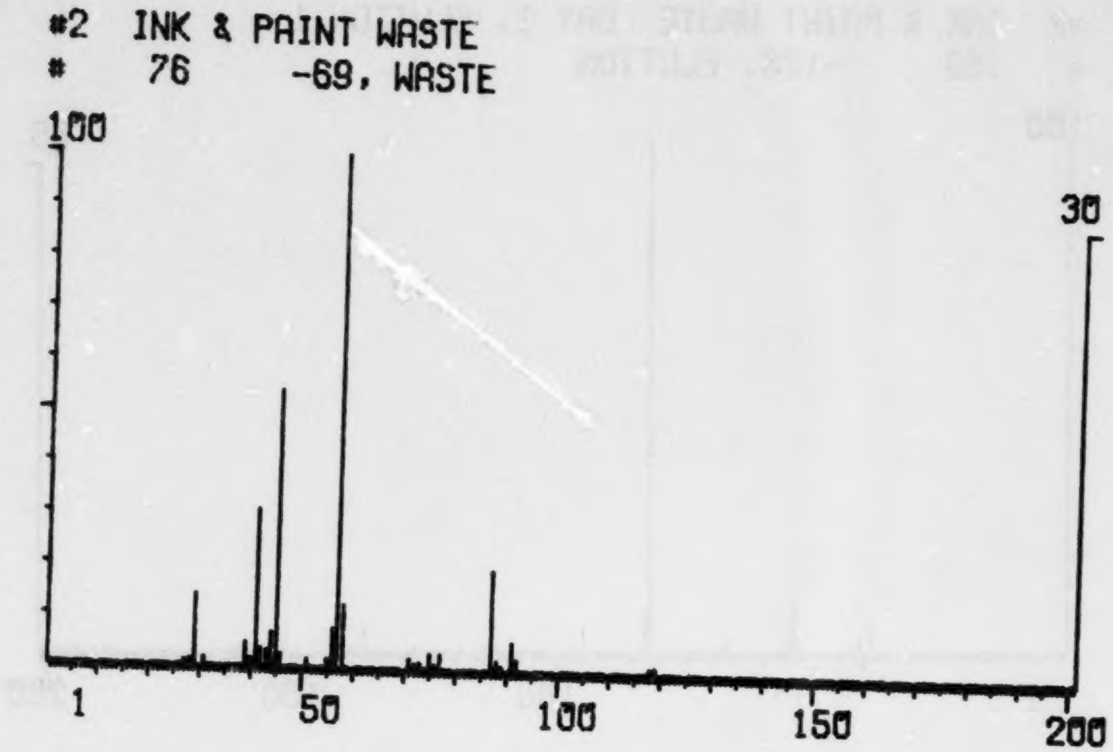

Figure A-5. Mass spectrum of 2-nor-butoxyethanol identified in Ink and Paint Waste hexane extract.

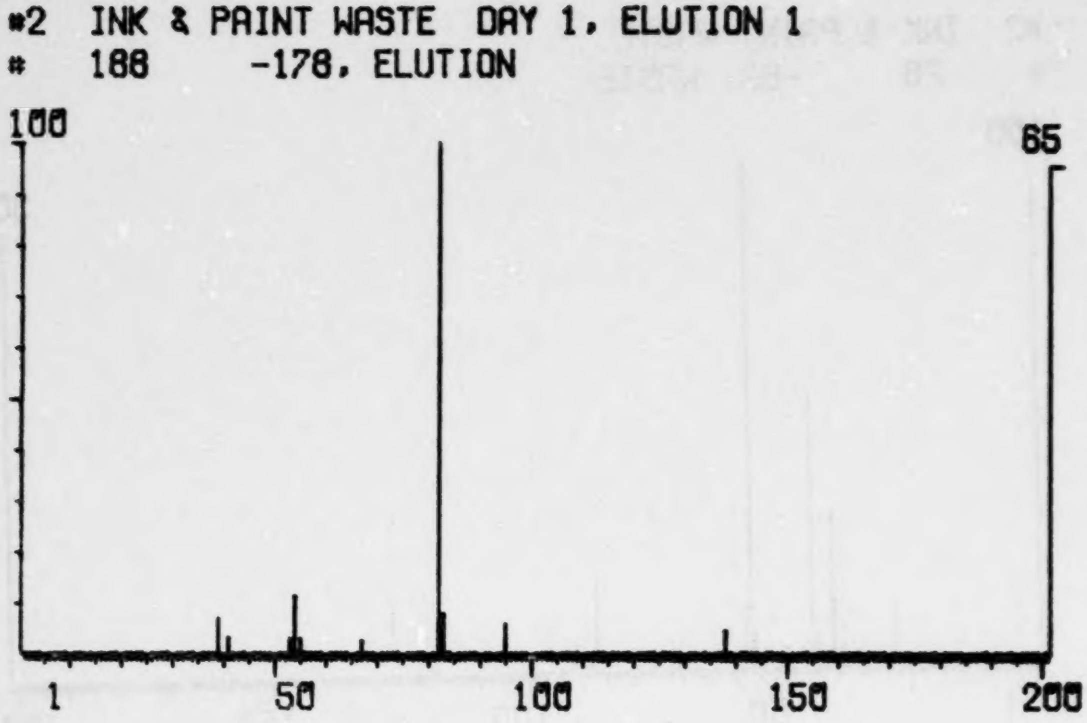

Figure A-6. Mass spectrum of 3,3,6-trimethyl bicyclo (3.1.0) hexan-2-one or 3,5,5-trimethyl-2-cyclohexanone identified in Ink and Paint Waste hexane extract.

(Spectrum in hexane extract was too close to background for a clear spectrum, so corresponding spectrum from SLT H_2O leachate, day 1, is presented.)

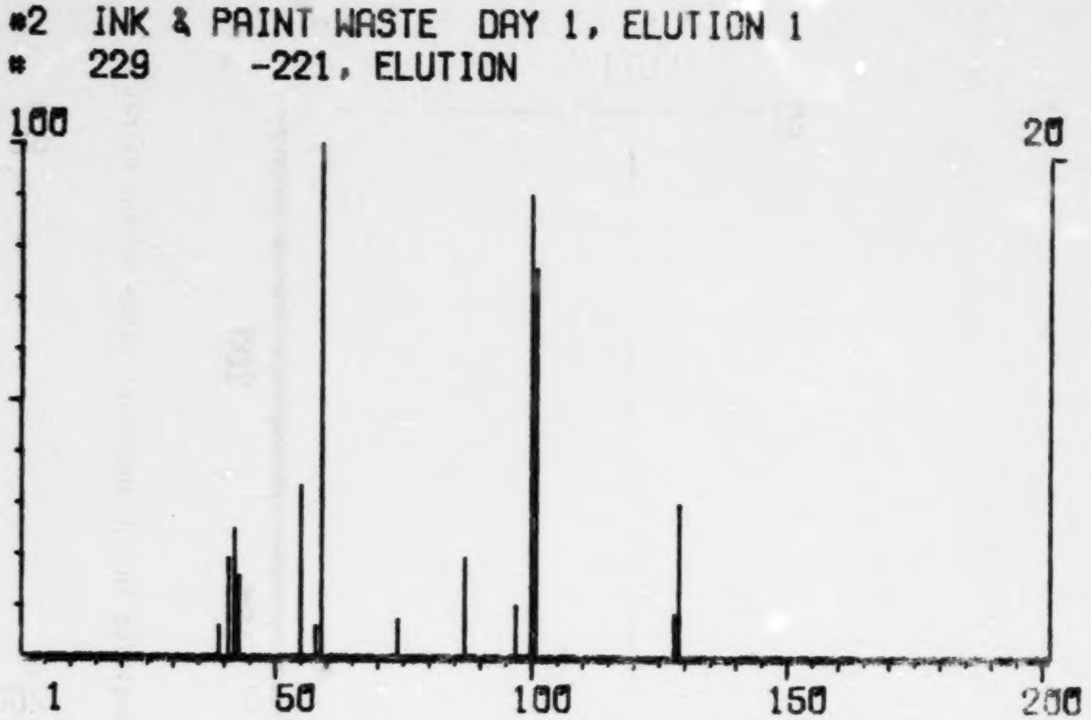

Figure A-7. Mass spectrum of dimethyl glutarate identified in Ink and Paint Waste hexane extract.

(Spectrum in hexane extract was too close to background for a clear spectrum, so corresponding spectrum from SLT H_2O leachate, day 1 is presented.)

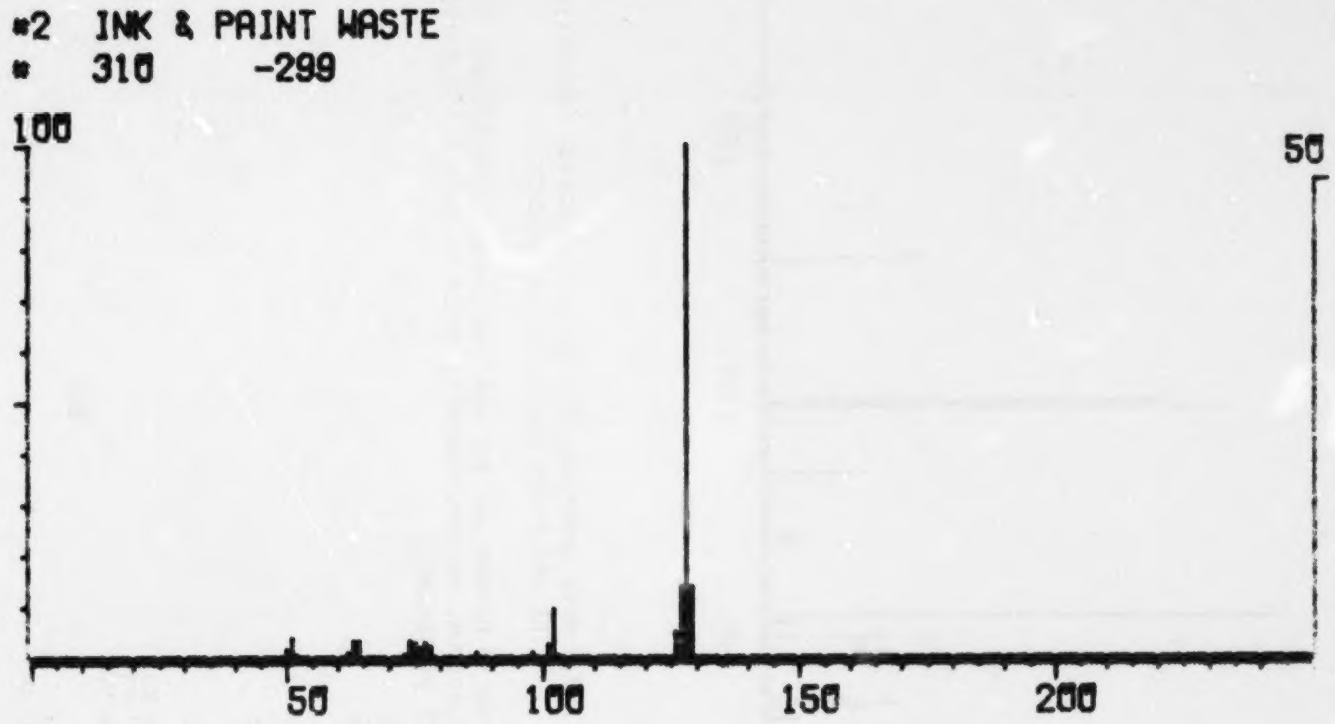

Figure A-8. Mass spectrum of napthalene identified in Ink and Paint Waste hexane extract.

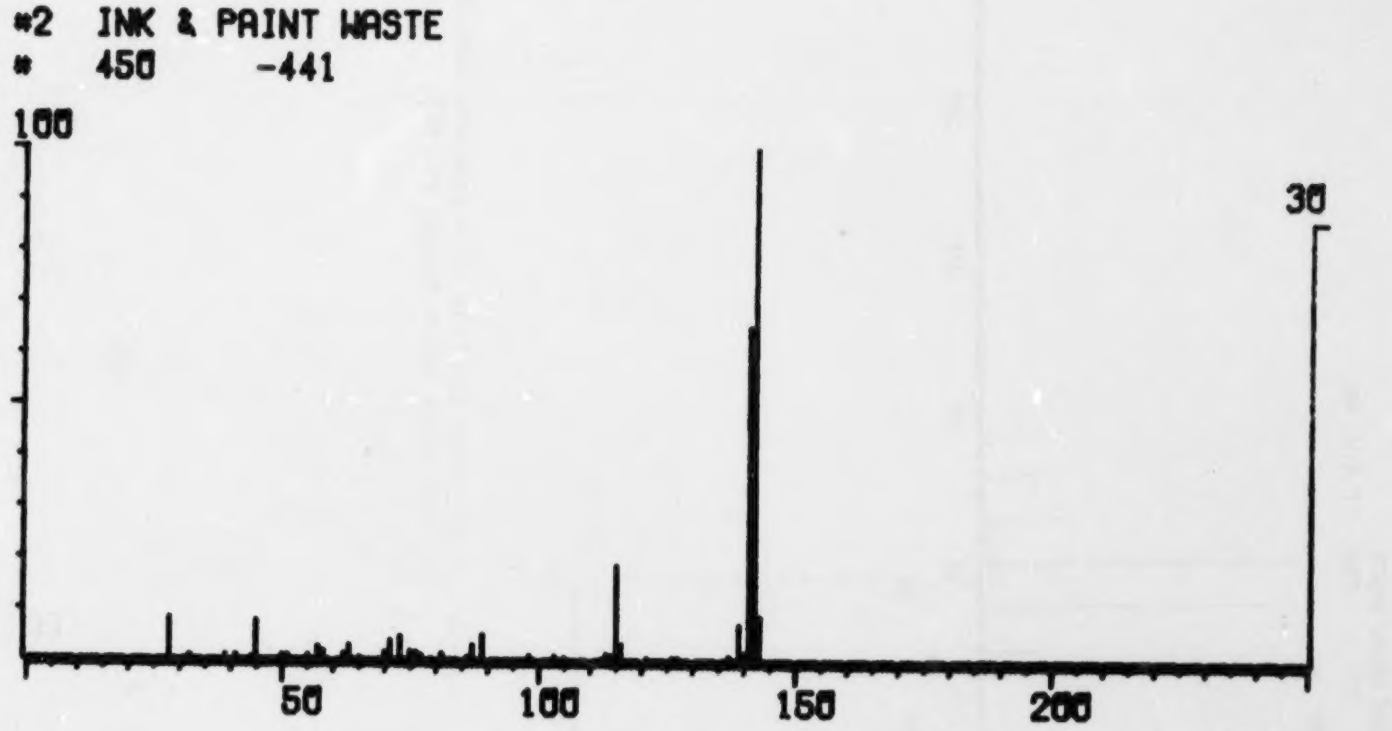

Figure A-9. Mass spectrum of methyl napthalene identified in Ink and Paint Waste hexane extract.

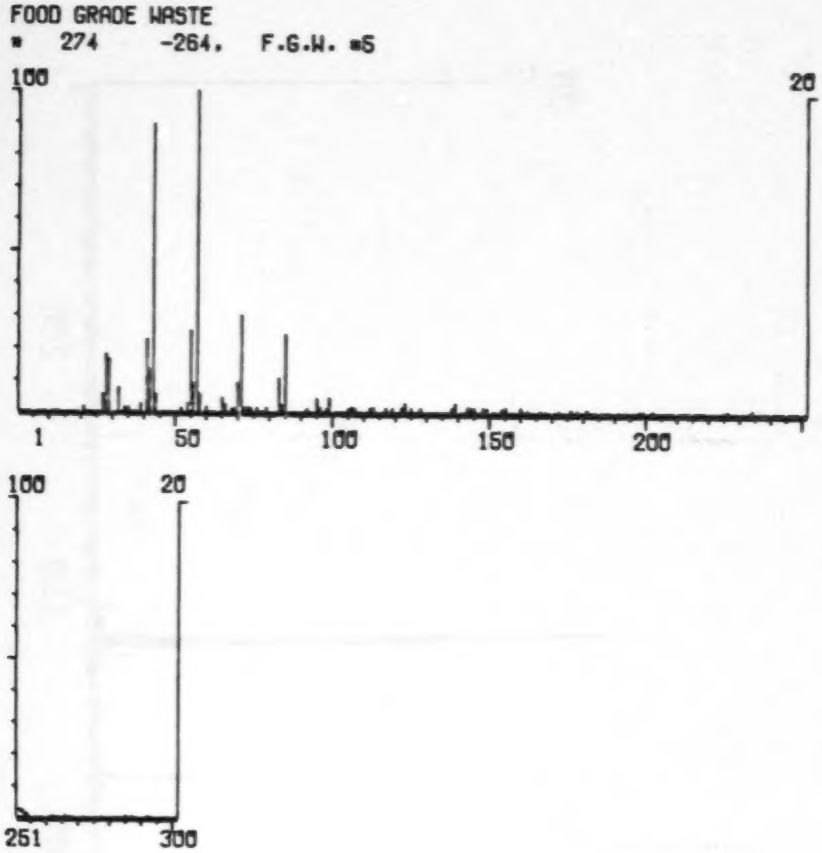

Figure A-10. Mass spectrum of octadecane identified in Food Grade Waste hexane extract.

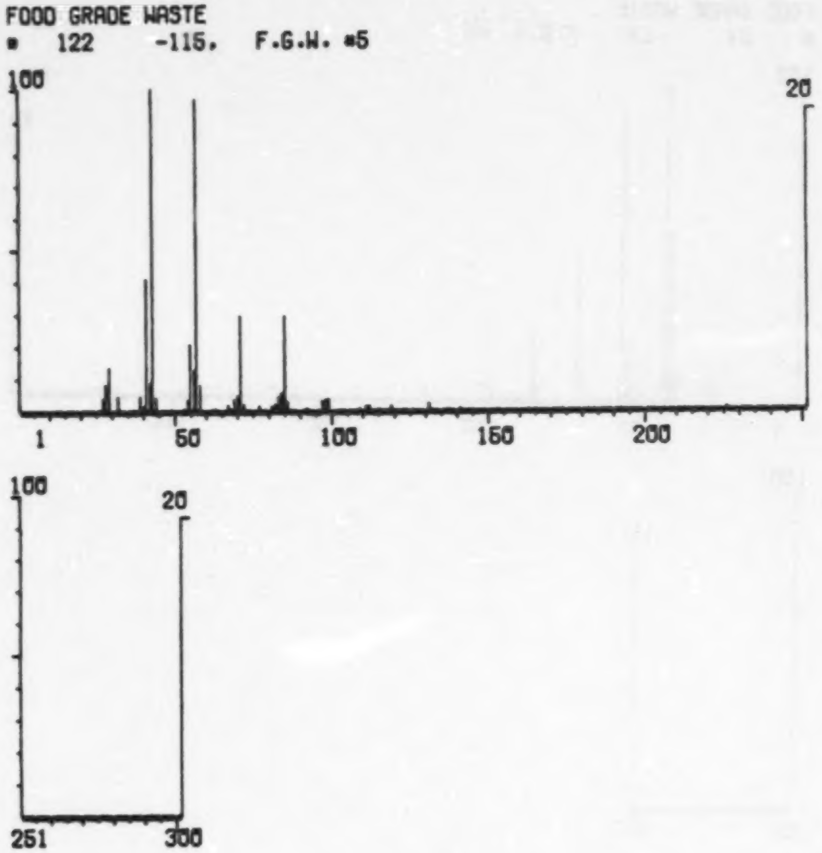

Figure A-11. Mass spectrum of hexadecane identified in Food Grade Waste hexane extract.

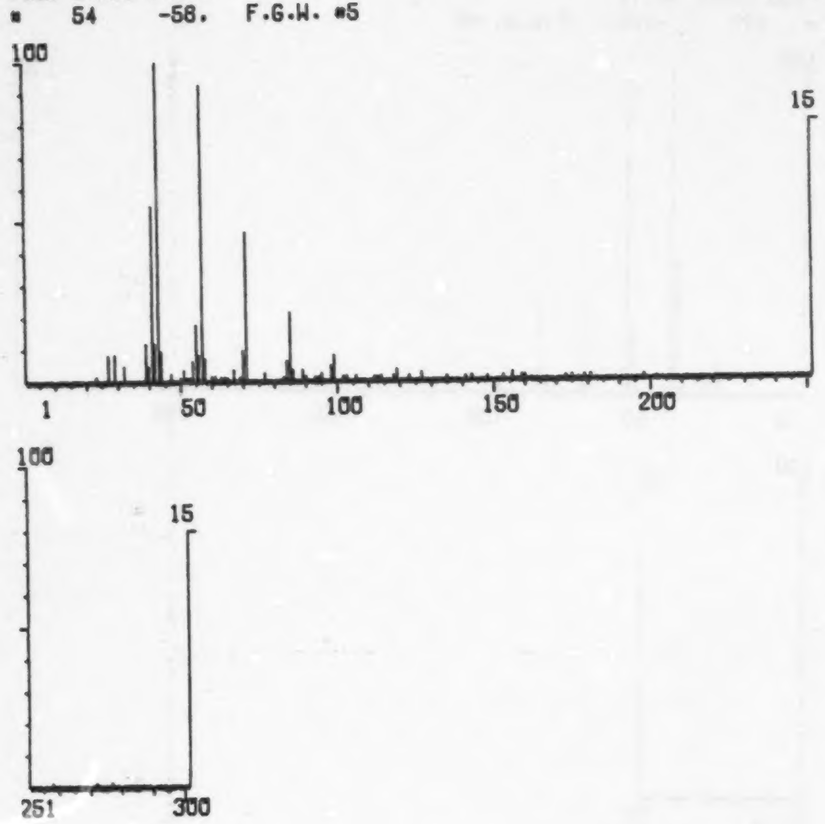

Figure A-12. Mass spectrum of tetradecane identified in Food Grade Waste hexane extract.

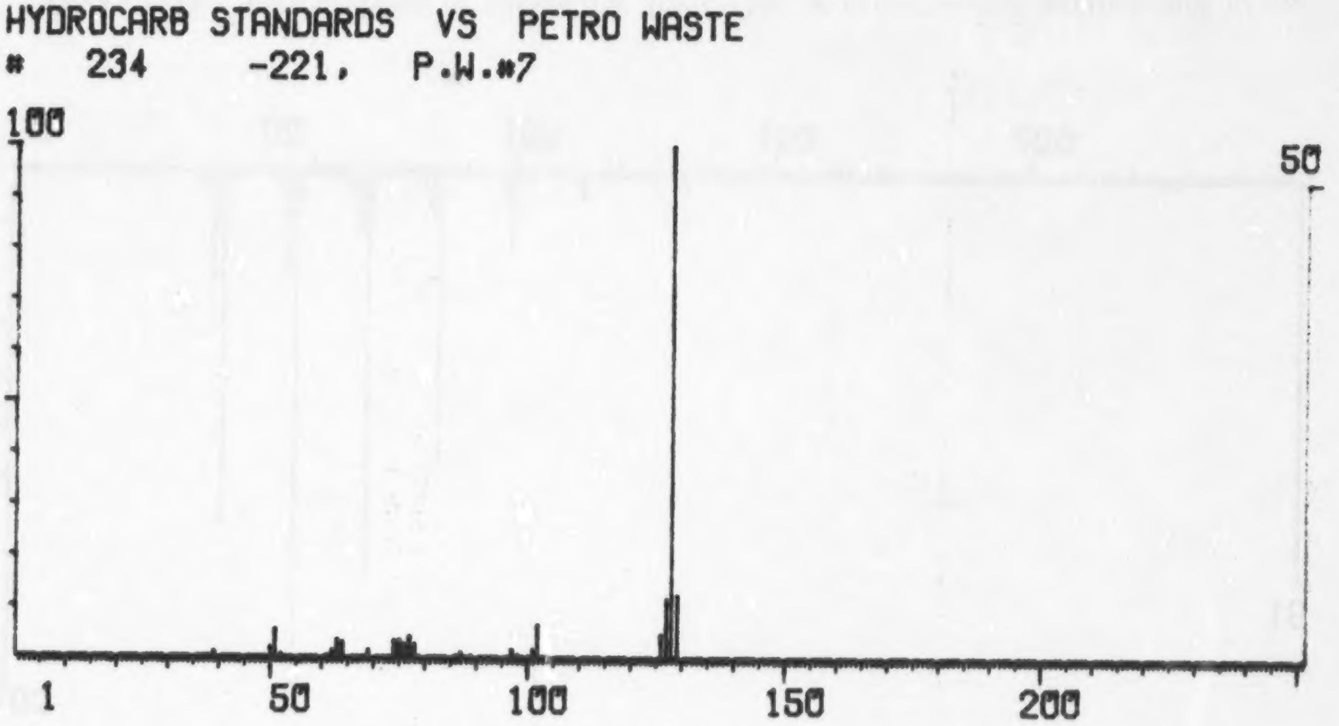

Figure A-13. Mass spectrum of napthalene identified in Petrochemical Waste hexane extract.

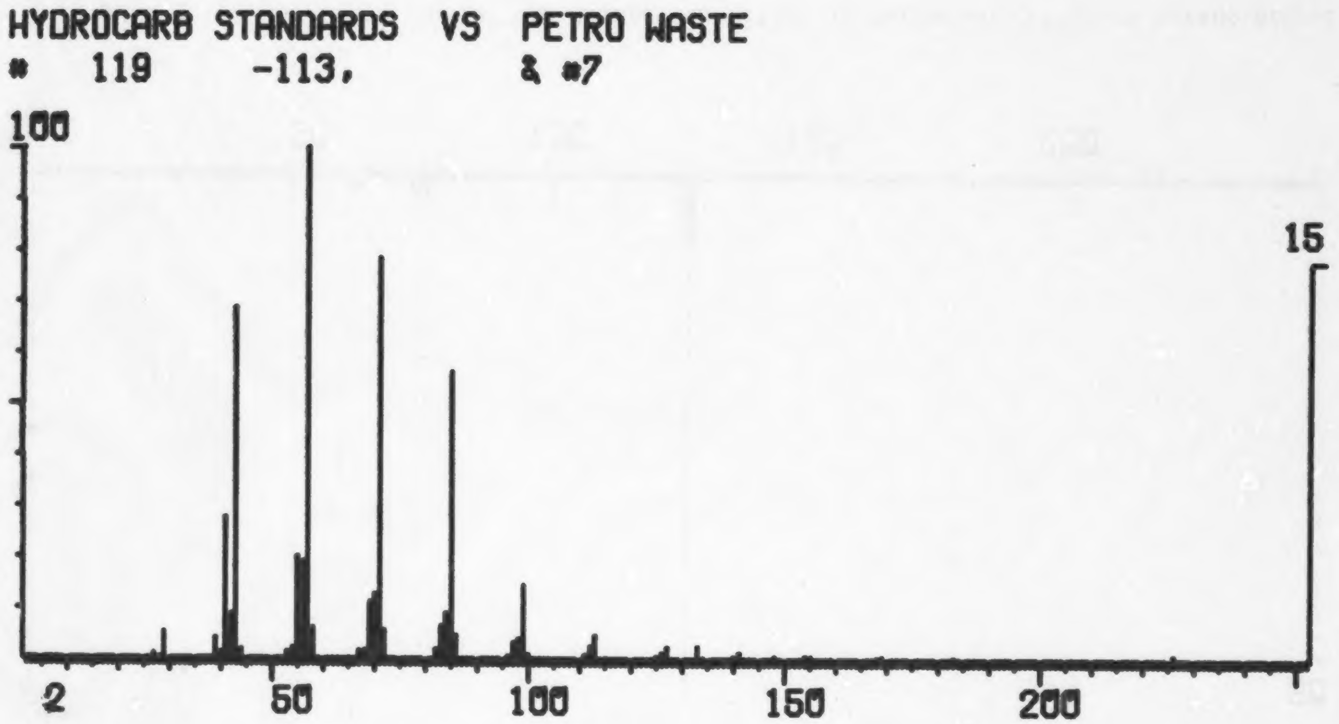

Figure A-14. Mass spectrum of hexadecane identified in Petrochemical Waste hexane extract.

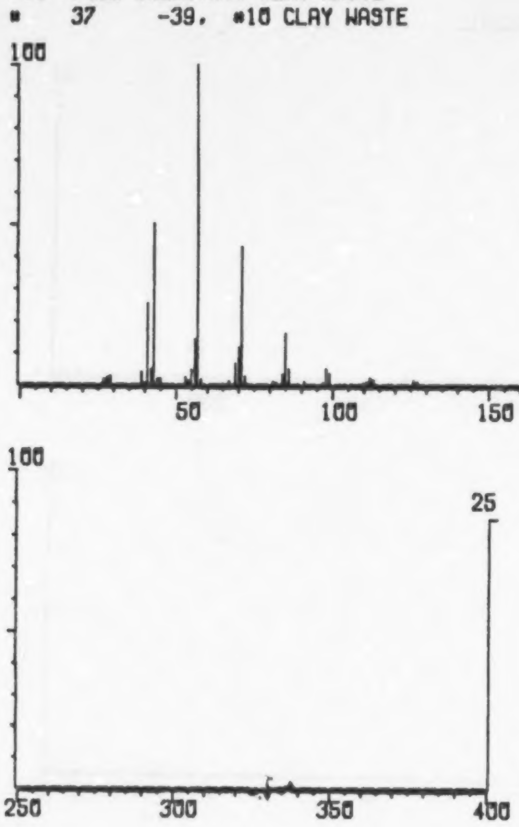

Figure A-15. Mass spectrum of dodecane identified in Food Industry, Clay Waste hexane extract.

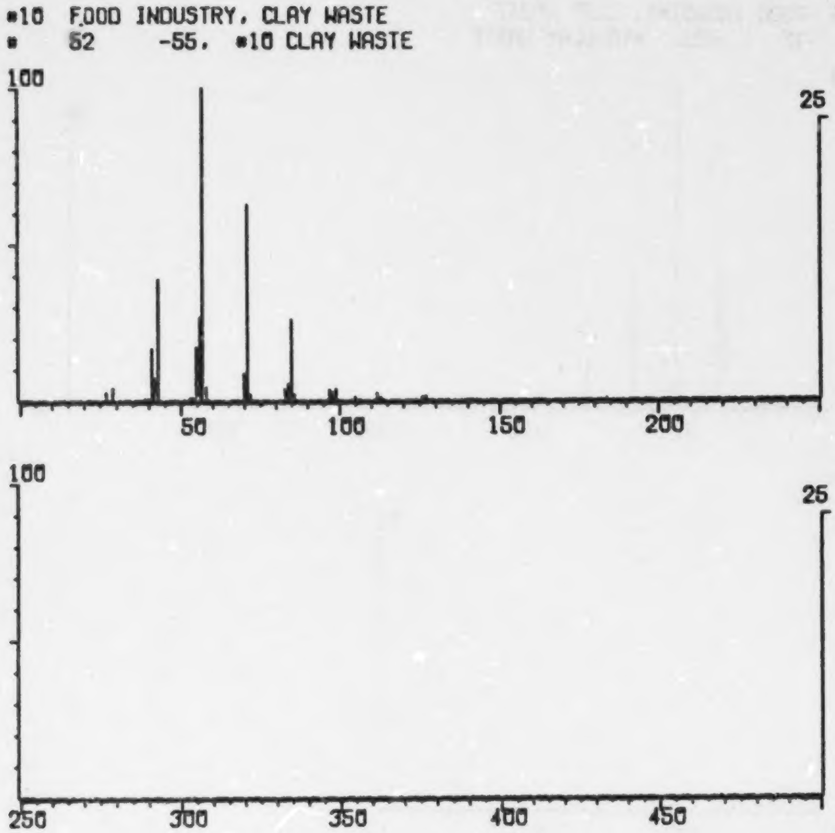

Figure A-16. Mass spectrum of tridecane identified in Food Industry Clay Waste hexane extract.

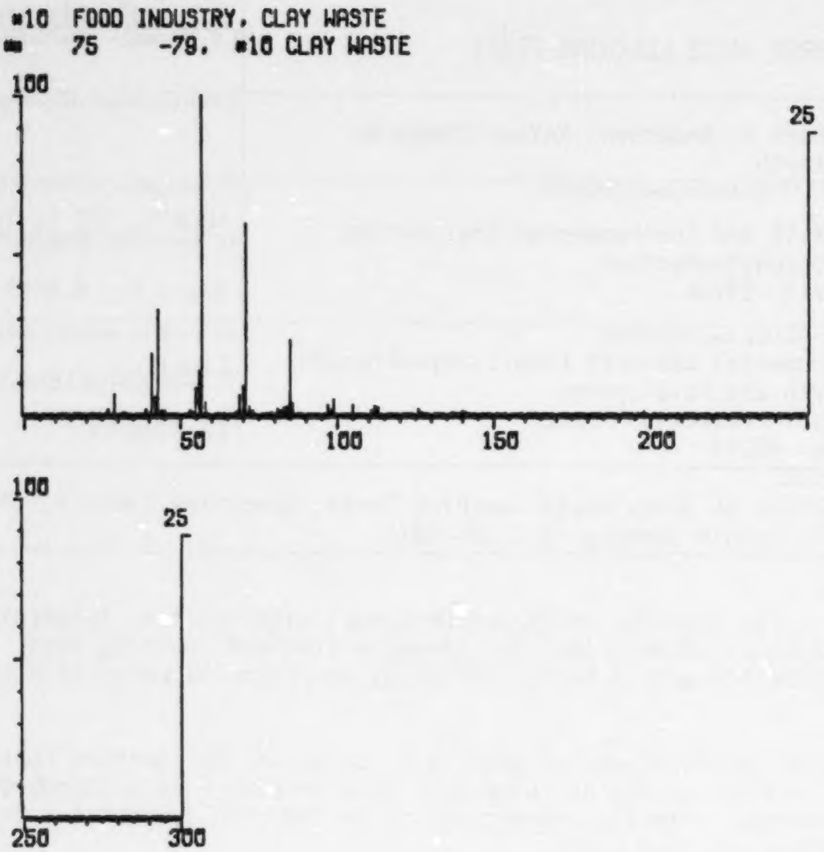

Figure A-17. Mass spectrum of tetradecane identified in Food Industry Clay Waste hexane extract.